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Image Gradation, Graininess and Sharpness in Television and Motion-Picture Systems

Part III: The Grain Structure of Television Images

By OTTO H. SCHADE

CONTENTS

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SYMBOLS

Note: Peak values are designated by a peak sign over a symbol $\hat{I}$; and average or mean values by a horizontal bar, $\bar{n}$. When used with $\bar{N}_e$-values, the bar indicates the geometric mean for two coordinates.

a	Area of sampling aperture
a_e	Equivalent sampling aperture
A	Frame area
b	Blanking factor (See Eqs. (61) and (72))
B	Luminance
c	A constant
C	Capacitance
d	Viewing distance
$\bar{e}$	Noise voltage
E_1	Exposure (unit: meter candle seconds)
E	Signal voltage
$[\bar{E}]$	Rms noise voltage
f	Frequency: $f(x,y)$ a function of x and y
Δf	Theoretical rectangular frequency channel (Eq. (63))
Δf_e	Noise-equivalent passband of electrical elements or systems
h	Horizontal dimension of equivalent sampling aperture or index for horizontal coordinate
H	Horizontal dimension of picture frame
$\bar{i}$	Noise current
I	Intensity or current
K	A constant
l	Unit of length
m	Horizontal bandwidth factor of electrical circuits (Eq. (79))
N	Line number — number of half-wavelengths of line- or sine-wave patterns per length unit
N_c	Limiting resolution, $N_{c(b)}$ limiting resolution of aperture system following raster process
N_e	Equivalent passband (Eqs. (22) to (28) Part II)
$\bar{N}_e$	Equivalent passband of an asymmetric aperture (Eq. (23) Part II)
$N_{e(a)}$	Equivalent passband of all apertures preceding and including analyzing aperture of raster process
$N_{e(b)}$	Equivalent passband of all apertures following and including synthesizing aperture of raster process
$\bar{N}_{e(f)}$	$= (N_{c(h)}n_r)^{\frac{1}{2}}$ Equivalent passband of theoretical television channel (Eq. (64))
$\bar{N}_{e(m)}$	$= (N_{e(h)}N_{e(v)})^{\frac{1}{2}}$ Equivalent optical passband of measuring aperture δ_m
$\bar{N}_{e(s)}$	$= (N_{e(h)}N_{e(v)})_s^{\frac{1}{2}}$ Equivalent optical passband of system between origin of deviations and point of observation
n	Number of particles or samples inside of sampling area
n_r	Raster constant, number of points or lines in length unit
n_s	Number of scanning lines including vertical blanking period (Eq. (62))
q_e	Electron charge
Q_f	Frame charge (Eq. (71))
r_ψ	Sine-wave response factor of an aperture (Eq. (18))
$r_{\bar{e}}$	Electrical sine-wave response factor (Eq. (65))
$r_{\psi a}$	Response factor of analyzing aperture (including preceding apertures)
$r_{\psi b}$	Response factor of synthesizing aperture (including following apertures)
$[r_\psi]$	Rms response factor
R	Resistance
$[R]$	Signal-to-rms-deviation ratio, static value in a single image frame (Eq. (13) Part II)
$[R]_m$	Reference signal-to-deviation ratio measured at the source with a known aperture δ_m
$[R]_s$	Signal-to-deviation ratio of system
s	Length of side of square aperture, or storage factor
t	Time interval
T_f	Frame time
v	Vertical dimension of equivalent sampling aperture or index for vertical coordinate
V	Vertical frame dimension
x,y	Coordinates, x = coordinate in the direction of scanning
Y	Amplitude
α	$=(\bar{N}_{e(s)}/N_c)_h$ Horizontal bandwidth factor (Eq. (66))
β	$=N_{e(s)v}/n_r$ Vertical bandwidth factor (Eq. (67))
$(\alpha\beta)^{\frac{1}{2}}$	$= (\bar{N}_{e(s)}/(N_{c(h)}n_r)^{\frac{1}{2}}$ Optical bandwidth factor (Eq. (68))
γ	Constant gamma
$\dot{\gamma}$	Point gamma, definition in Part I, p. 145
$\dot{\gamma}_s$	Point gamma of system at a particular signal level between origin of deviations and point of observation
δ	Characteristic aperture diameter
δ_f	Equivalent optical aperture of theoretical television channel (Fig. 80)
ϵ	Base of natural logarithm
τ	Transmittance
σ	Relative deviation (Eqs. (13) to (17) Part II)
θ	Phase displacement between sample amplitude and crest intensity $\hat{I}_N$ (Fig. 69)
ψ	Flux
$[\bar{\psi}]$	Rms value of variational (a-c) flux (see Eq. (20))

SUMMARY OF PART III

The analysis of grain structures in imaging systems containing a point- or line-raster process requires evaluation of the sine-wave response in two coordinates. The characteristics of the raster process are developed by a Fourier analysis of the optical image. The sine-wave response perpendicular to the raster lines (for example the vertical sine-wave response of a television system) is shown to contain in general a carrier wave, the normal aperture response to sine-wave test signals, and a series of sum-and-difference components with magnitudes depending on the aperture response products of the analyzing and synthesizing apertures preceding and following the raster process (camera tube and kinescope in television systems). A graphic representation of the raster equation (Fig. 70) shows at a glance the number and magnitude of the sine-wave components for any combination of apertures used with the raster process. The application of the aperture theory developed in Part II yields an equivalent optical aperture (Fig. 80) and equivalent passband (Eq. (64)) for the theoretical television channel. The evaluation of the horizontal sine-wave response of electro-optical systems containing electrical and optical elements is simplified by establishing normalized characteristics for the sine-wave response, equivalent passband, aperture cross section, and edge transition of a variety of electrical response characteristics (including aperture correction) in cascade with optical apertures. Because of their general character and use in the evaluation and design of television systems, the range of parameters has been extended beyond the cases used in examples.

In normalized units equivalent passbands (horizontal and vertical) of electrooptical systems are specified by bandwidth factors (α and β), which are ratios of the equivalent passband of the system to the theoretical passbands $N_{e(h)}$ and n_v of the television channel (section D_1). These bandwidth factors emerge as significant parameters specifying the characteristics of the system.

The translation of electrical noise levels into optical deviations in a television frame is now readily accomplished, permitting evaluation of granularity by the methods discussed in Part II. It is shown that the electrical signal-to-noise ratios usually quoted for television systems have by themselves little meaning when television grain structures are compared, because the transfer characteristics and apertures of the system cause pronounced changes in signal-to-deviation ratios and the amplitude of the sine-wave components contained in optical deviations of a television picture frame. It is concluded that an adequate description of granularity in television and motion-picture frames requires specification of the sine-wave spectrum and signal-to-deviation ratio in the retinal image as a function of luminance and for a specified viewing distance. An assessment of the perception of deviations throughout the luminance range of motion pictures and television images can be made by introducing the characteristic of threshold signal-to-deviation ratios as a reference level.

A. REVIEW OF PRINCIPLES

The principles and method developed in the analysis of motion-picture granularity in Part II of this paper can be applied to all imaging systems and will be summarized briefly. Random fluctuations of luminance in motion-picture or television images cause the appearance of a moving granular structure. In a single picture frame representing a constant light level the structure is stationary

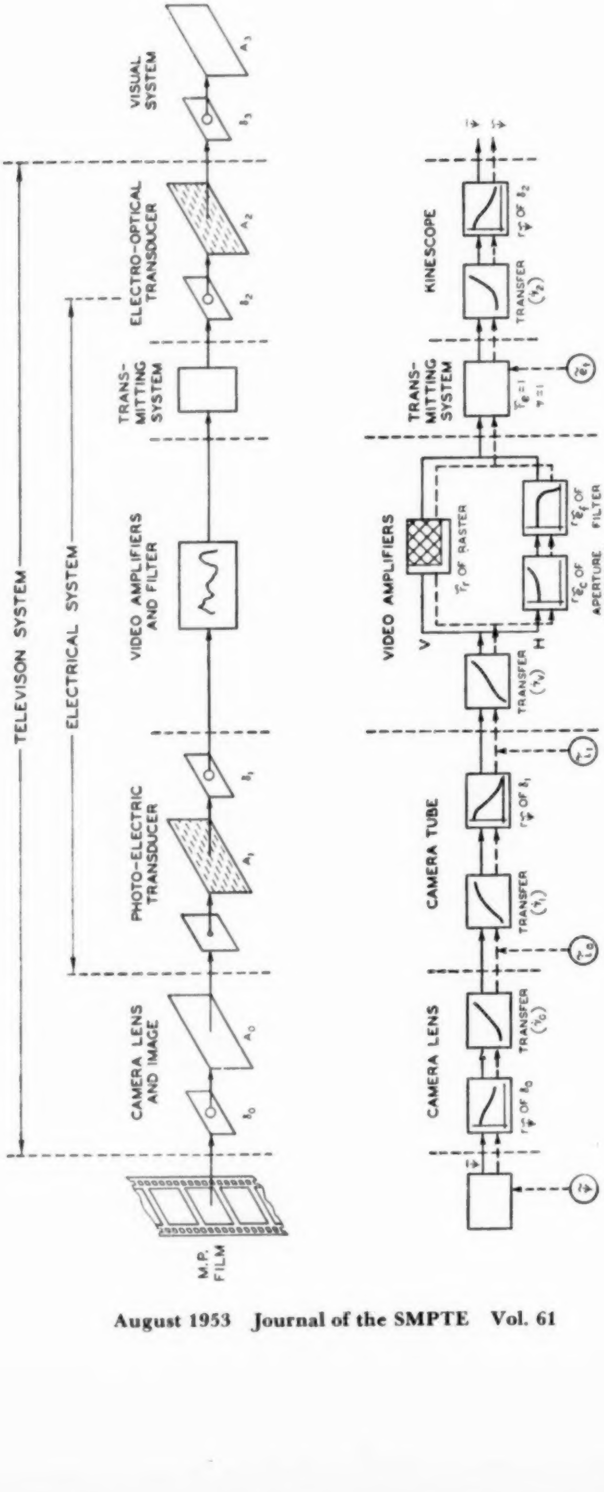


Fig. 65. Block diagram of television process and sources of random deviations.

and the luminance variations are *static deviations* from the average luminance which is the *optical signal.*

Optical signals and deviations are measured by taking samples of the image flux with an aperture. The average value of the sample readings is the signal. The relative magnitude of the deviations is expressed by the *relative deviation* σ or its reciprocal, the *signal-to-rms deviation ratio* $[R]$. When the deviations are random (see Part II for definition) the value $[R]$ measured at the source of deviations is directly proportional to the one-half power of the effective area a_e of the sampling aperture as stated by

$$[R] = 1/\sigma = (\bar{n}_0 a_e)^{\frac{1}{2}}$$

where $\bar{n}_0$ specifies the mean "particle" density in the random structure at the source. The effective sampling area of practical image-forming devices or systems can be determined from the geometry of their point image (see Part II) or from the total sine-wave energy response of the point image, obtained by a Fourier analysis of a test image such as a single sharp line, a single-edge transition, a random grain structure, or from sine-wave test patterns. The last two methods mentioned, particularly the method using sine-wave test patterns with variable line number, are known from analogous electrical measurements to be most accurate because of the high energy level of the observed signals and the simplicity of evaluation. In sine-wave response measurements the point image is regarded as an "aperture" of unknown geometry which is made to scan a series of constant-energy sine-wave test patterns. The total relative sine-wave energy of the aperture response characteristic is specified by a single number N_e interpreted as an *equivalent passband.* The reciprocal of this measure K/N_e specifies the diameter of the desired *equivalent sampling aperture* (see Table VII, Part II). The point images of practical devices are often asymmetric. In this case the equivalent sampling aperture can be specified as a rectangle with the dimensions h and v, which are the reciprocals of two equivalents:

$$a_e = hv = [Ne_{(h)}Ne_{(v)}]^{-1} \qquad (51)$$

The asymmetric point image is described by two sine-wave response characteristics in rectangular coordinates (H and V) and their corresponding equivalent passbands $N_{e(h)}$ and $N_{e(v)}$.

The signal-to-deviation ratio $[R]$ can now be stated in the forms

$$[R] = \bar{n}_0^{\frac{1}{2}}/[N_{e(h)}N_{e(v)}]^{\frac{1}{2}}$$
$$[R] = \bar{n}_0^{\frac{1}{2}}/\bar{N}_e \qquad (52)$$

where $\bar{N}_e$ is the geometric mean of the two equivalent passbands.

The particle density $\bar{n}_0$ *at the source* can be determined by a count of the number of particles (grains or electrons) in a unit area of the random structure in which the deviations originate. When this is impractical, $\bar{n}_0$ is obtained from a reference value $[R]_m$ measured or computed with an aperture of known area a_m or equivalent passband $\bar{N}_{e(m)}$.

The actual signal-to-deviation ratio $[R]_s$ at any one point in the imaging system can then be computed accurately from the aperture ratio (Eq. (37) in Part II) which, stated in terms of N_e-values, has the form

$$[R]_s = [R]_m(\bar{N}_{e(m)}/\bar{N}_{e(s)})/\dot{\gamma}_s \qquad (53)$$

where

$[R]_m$ = signal-to-deviation ratio at the origin of deviations, measured with an aperture of equivalent passband $\bar{N}_{e(m)}$

$\bar{N}_{e(m)} = (N_{e(h)}\,N_{e(v)})_m^{\frac{1}{2}}$ = equivalent optical passband of measuring aperture

$\bar{N}_{e(s)} = (N_{e(h)}N_{e(v)})_s^{\frac{1}{2}}$ = equivalent optical passband of system aperture between origin of deviations and point of observation

$\dot{\gamma}_s$ = overall transfer ratio or "point gamma" of system elements at the particular signal intensity between origin of deviations and point of observation.

The analysis of optical deviations in television images requires a translation of

television system parameters and characteristics into equivalent optical units. A schematic representation of a television process is shown in Fig. 65. The light flux in the optical image A_0 formed by the camera lens is transduced into an electrical image A_1 in the television camera tube. The charge image A_1 is scanned by an aperture δ_1 along a system of parallel lines termed a *line raster*. The aperture δ_1 is the electron beam of the camera tube which transduces the electrical aperture flux into video signals. The electrical signals are amplified, limited by electrical filters, transmitted and again transduced into light-flux variations by the aperture δ_2 of an electro-optical transducer (kinescope) scanning the frame area A_2. The two scanning apertures δ_1 and δ_2 are moved with uniform velocity and in synchronism over the respective frame areas. Like optical apertures, these scanning apertures have two dimensions, and their response is readily described by normal sine-wave response characteristics and equivalent passbands. New elements in the imaging system requiring evaluation in terms of optical response characteristics are the *line raster* and the electrical system of amplifiers and low-pass filters.

Luminance deviations in a television frame may be caused by a number of sources located at different points in the system (see Fig. 65). When the deviations originate in a preceding photographic process, the television system is an aperture process transferring a two-dimensional granular structure. Deviations originating in electrical elements, however, may not be associated with the transferred image. Electron sources such as the cathodes of electron guns or amplifier tubes continually produce random fluctuations in the flow of electrons, which are arranged and displayed artificially in two dimensions by the scanning process. The resulting luminance deviations in the frame area may, however, be regarded as the image of a random particle structure scanned with a hypothetical camera and measured with a theoretical sampling aperture $\delta_{(f)}$ which will be found to have a specific value given by the system constants. With this concept all cases can be treated by one method.

B. RASTER PROCESSES

1. The Raster Constant (n_r)

The formation of images by lenses or optical systems is continuous in both coordinates of the image area. It is, therefore, permissible to determine signals and deviations from a limited number of sample readings, because every point in the image area undergoes an aperture process. The aperture shape becomes indistinguishable in areas of constant luminance. In the presence of deviations, the steady "signal" flux can be considered as a "carrier" flux of constant intensity $\bar{I}$ "modulated" by random deviations.

Printing, facsimile and television are sampling processes in which the number of aperture positions is finite in one or both coordinates of the image frame. The image flux is no longer continuous in two coordinates but contains periodic components. An arrangement limiting aperture positions to a fixed number of uniformly spaced points in the image frame is termed a *point raster;* an arrangement providing continuous aperture positions along uniformly spaced parallel lines is termed a *line raster*. *The "raster" constant n_r specifies the number of aperture positions in the length unit of a geometric arrangement of points or lines;* it does not specify the dimensions of the "points" or "lines" themselves which are determined by the geometry of the sampling apertures used with the raster process.

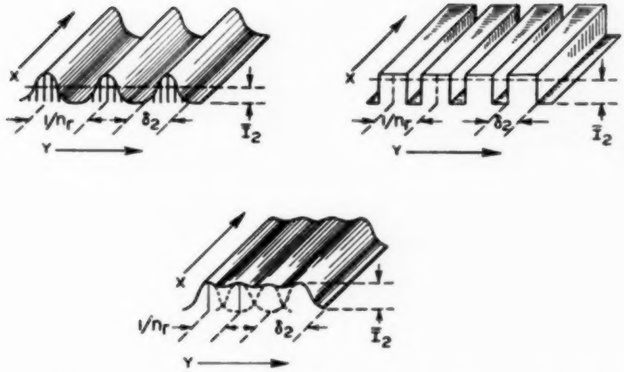


Fig. 66. Intensity distribution and "carrier" waves in the y-coordinate of line-rasters.

2. Carrier Wave and Line Structure

A line raster limits the number of aperture positions perpendicular to the raster lines. Areas of constant luminance are reproduced by the aperture δ_2 as a flux pattern in which the intensity is constant in the direction x parallel to the raster lines but contains a more or less pronounced periodic component in the y-coordinate defined as the coordinate perpendicular to the raster lines (Fig. 66). The following analysis of conditions in the y-coordinate of a line raster applies to optical as well as television processes† and also to point rasters which cause periodic components in both x- and y-coordinates. (In television images the coordinate Y is identical with the vertical coordinate V of the image frame.)

The periodic component can be regarded as a constant *carrier wave* added by the raster to the continuous carrier flux of a normal aperture process. The signal flux from the analyzing aperture δ_1 determines the average intensity level $\bar{I}$, i.e., the scale factor of the image flux. It is seen by inspection of Fig. 66 that the length of the carrier wave is the reciprocal of the raster constant: $\Delta y = 1/n_r$, while waveform and relative amplitude of the carrier wave are determined by the geometry of the synthesizing aperture δ_2.

A Fourier analysis of this "pulse carrier wave" shows that the intensity distribution $I_{(y)} = f(y)$ contains the constant signal term $\bar{I}$ and a series of harmonic cosine waves:

$$I_y = \bar{I}[1 + \sum_p 2r_{\psi(pn_r)} \cos p\pi y n_r] \quad (54)$$

$(p = 2, 4, 6, \ldots)$

The cosine terms specify the harmonic components of the carrier wave, which have (television) line numbers $N_{r1} = 2n_r$, $N_{r2} = 4n_r$, $N_{r3} = 6n_r$, ... Their relative intensities are specified by coefficients which are the *sine-wave response factors* $r_{\psi(\ldots)}$ in the y-coordinate of the particular aperture δ_2 at the line numbers of corresponding carrier harmonics. The cosine-wave components are in phase at the aperture center (on the raster line) when the aperture has axial symmetry† and its response decreases asymptotically to zero. When the response characteristic has an oscillatory form (compare Figs. 41 and 42 of Part II), the phase may reverse at each zero re-

† A two-dimensional Fourier analysis of the television picture was presented in an early paper by Mertz and Gray.[1]

† Apertures with asymmetric cross sections introduce phase shifts between cosine terms and will be discussed in Part IV.

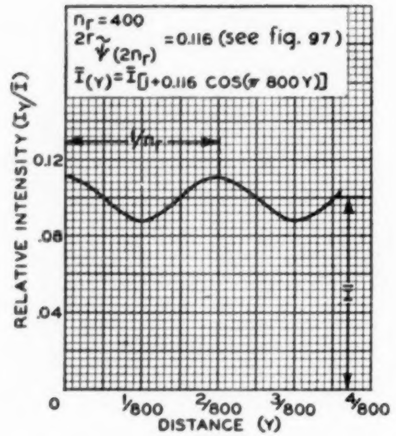


Fig. 67. Intensity distribution in y-coordinate of raster process with kinescope aperture $\delta_2 > 1/n_r$ passing only one cosine term of the carrier wave.

sponse point. Examples illustrating a numerical synthesis of the intensity distribution expressed by Eq. (54) are shown in Figs. 67 and 68. Equation (54) establishes a direct relation between the geometry of the *line image* and the sine-wave response characteristic of the line-generating point image. For the purpose of reconstructing an aperture cross section (i.e. an isolated line) from its sine-wave spectrum the fundamental component $N_{r1} = 2n_r$ in Eq. (54) is given a low value for which the bracketed terms of Eq. (54) equal zero at the distance $y = \frac{1}{2}n_r$. This condition is obtained when

$$2(r_{\tilde{\psi}(2n_r)} - r_{\tilde{\psi}(4n_r)} + r_{\tilde{\psi}(6n_r)} - \ldots) = 1 \quad (55)$$

A fundamental component $N_r = 2n_r = 200$ lines was used for the aperture synthesis (Fig. 68) from the sine-wave response characteristic (Fig. 95).

The presence of a pronounced line structure in the image is highly undesirable. Perfect continuity is restored when none of the carrier-wave components are reproduced by the aperture δ_2, i.e., when the aperture response is zero at line numbers which are integral multiples of $2n_r$. Practical imaging devices usually have an aperiodic response characteristic. In some cases the response has nonintegral zeros, but the response is usually low beyond the first zero. A substantially continuous or "flat" field is, therefore, obtained when

$$r_{\tilde{\psi}(2n_r)} \lesssim 0.005 \quad (56)$$

This response factor causes a ripple amplitude of 1%, i.e., a peak-to-peak intensity variation of 2%. The aperture process δ_2 in the reproducing device (kinescope) is followed by other imaging processes, for example by the process of vision or by a photographic process. It is, therefore, unnecessary to restrict the response of the aperture δ_2 alone by Eq. (56) but rather the overall sine-wave response $r_{\tilde{\psi}b}$ of the aperture system following the raster process (indicated by the index b).

The flat-field condition specified by Eq. (56) may be stated in the form

$$N_{c(b)} \lesssim 2n_r \quad (56a)$$

Assume for example that a standard 35-mm motion-picture process (Table IX (1 to 4), Part II) which has a limiting resolution N_c of approximately 1100 lines, is used for video recording. It follows from Eq. (56a) that a standard 525-line television raster which contains $n_r = 490$ active line traces is just resolved in the optical projection of the 35mm print. Even with a kinescope having 3000-line resolution and an aperture response $r_{\tilde{\psi}(2n_r)} = 0.62$ which causes a pronounced line structure on the kinescope screen, the response in the optical 35mm projection is only 1% at $N = 2n_r$.† The carrier "ripple" has then an amplitude of 2% and a peak-to-peak amplitude of 4%.

† Failure to interlace perfectly will introduce carrier components at one-half the line number, for which the overall response is 22%.

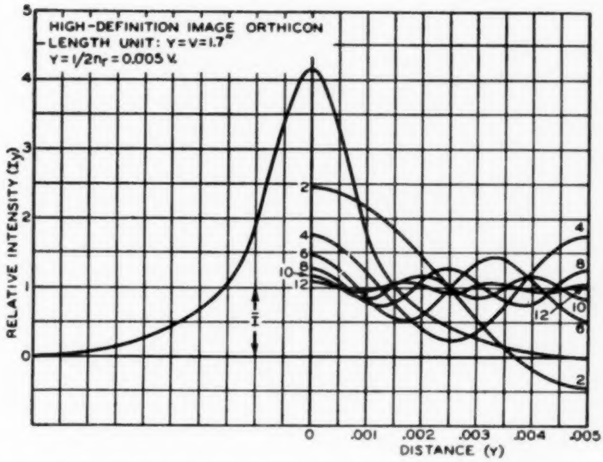


Fig. 68. Synthesis of line cross section formed by a camera-tube scanning beam for the condition $\delta \leq 1/n_r$ (nonoverlapping).

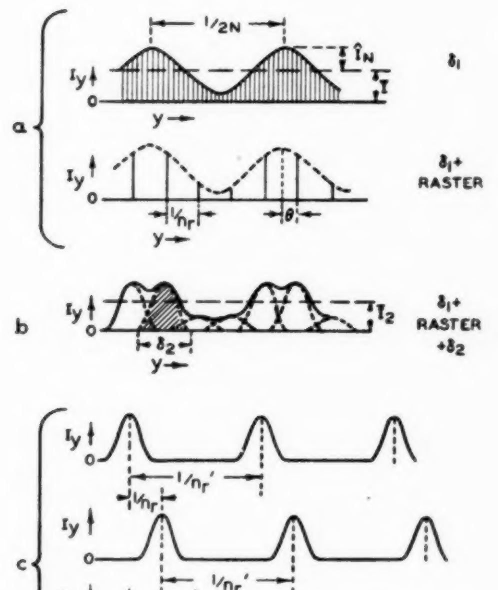


Fig. 69. Sampling and reproduction of sine-wave test pattern in the *y*-coordinate by a raster process and development of raster equation by regarding "modulated" carrier wave as the sum of interlaced carrier waves with different amplitudes.

3. Response to Sine-Wave Test Patterns and Equivalent Passband

A line raster has no effect on the sine-wave response of the apertures δ_1, and δ_2 in the x-coordinate (parallel to the raster lines), in which the aperture process is continuous. The discrete aperture positions in the y-coordinate affect the response of the two apertures in a different manner.

The analyzing aperture δ_1 "samples" the flux of a test pattern in the y-direction at the raster points only, all other aperture positions are "blocked" by the raster. What is left of the normally continuous aperture signal is a series of exact samples of its response at regularly spaced distances $\Delta y = 1/n_r$ as indicated by Fig. 69a. The reader may visualize the raster as an opaque plate with very fine slits (holes for a point raster) through which he, or a photoelectric device, views the test pattern from a fixed distance. He can control δ_1 by varying the spacing between the raster plate and the test object. When the test pattern line number N is varied, the sample amplitudes vary in direct proportion to the normal sine-wave response of δ_1. A further interpretation of these amplitudes cannot be given without considering the synthesizing aperture process.

For a linear system, the intensity of the light flux from the synthesizing aperture δ_2 is proportional to the signal amplitude delivered by δ_1 at corresponding raster points. The reproduced waveform, however, is only an artificial approximation of the test pattern wave, determined by the raster constant and the geometry of the aperture δ_2 as illustrated in Fig. 69b. The fundamental sine-wave response and the waveform distortion can be evaluated by a Fourier analysis. For this purpose the periodic wave may be regarded as the sum of a series of interlaced carrier waves, each having a constant amplitude and a wavelength $1/n_r'$ which is longer than the normal raster period (see Fig. 69c). These component carrier waves are displaced in phase by distances $1/n_r$, $2/n_r$ etc., with respect to one another and can be expressed by Fourier series (Eq. (54)) differing only in amplitude and phase of the terms. A vectorial addition of corresponding terms yields an expression for the waveform. For the conditions that the average intensity $\bar{I}_2$ in the image of the test pattern has the same numerical value as the test pattern intensity $\bar{I}$, and the transfer ratio of signals (gamma) is unity, the expression obtained for the intensity $I_{(y)^2} = f(y)$ is the following Eq. (57):

$$
\begin{aligned}
I_{(y)2} = \bar{I}[1 + \sum_p 2r\psi_{(pn_r)} \cos p\pi y n_r] \quad & \text{(C)} \\
+ \hat{I}_N r\psi_1 r\psi_2 \cos [(N/n_r)\pi y n_r + \theta] \quad & \text{(N)} \\
+ \hat{I}_N r\psi_1 \sum_p r\psi_{(pn_r+N)} \cos [(p + N/n_r)\pi y n_r + \theta] \quad & \text{(S)} \\
+ \hat{I}_N r\psi_1 \sum_p r\psi_{(pn_r-N)} \cos [(p - N/n_r)\pi y n_r - \theta] \quad & \text{(D)}
\end{aligned}
$$

where

p = 2, 4, 6, . . .
n_r = Raster constant (number of sampling positions per length unit)
y = Distance along y-coordinate (same length units as $1/n_r$)
$\bar{I}$ = Average intensity in y-coordinate
$\hat{I}_N$ = Crest intensity of sine-wave flux in test pattern
$r\psi_1$ = Response factor of aperture δ_1 at the line number N
$r\psi_2$ = Response factor of aperture δ_2 at the line number N
$r\psi_{(\text{index})}$ = Response factor of aperture δ_2 at line number indicated by index
θ = Phase displacement between sample amplitude and crest $\hat{I}_N$ (Fig. 69).

The terms of Eq. (57) have been arranged in four products. The first product (C) contains only the *steady carrier components* as expressed by Eq. (54). The magnitude and numbers of the sine-wave terms depend on the aperture response of δ_2 only. The second product (N) is identified as the *normal sine-wave signal flux* ψ_{12} of the cascaded aperture δ_1 and δ_2 at the line number N. The third and fourth products (S) and (D) are harmonic components with line numbers which are the *sums and differences* of the

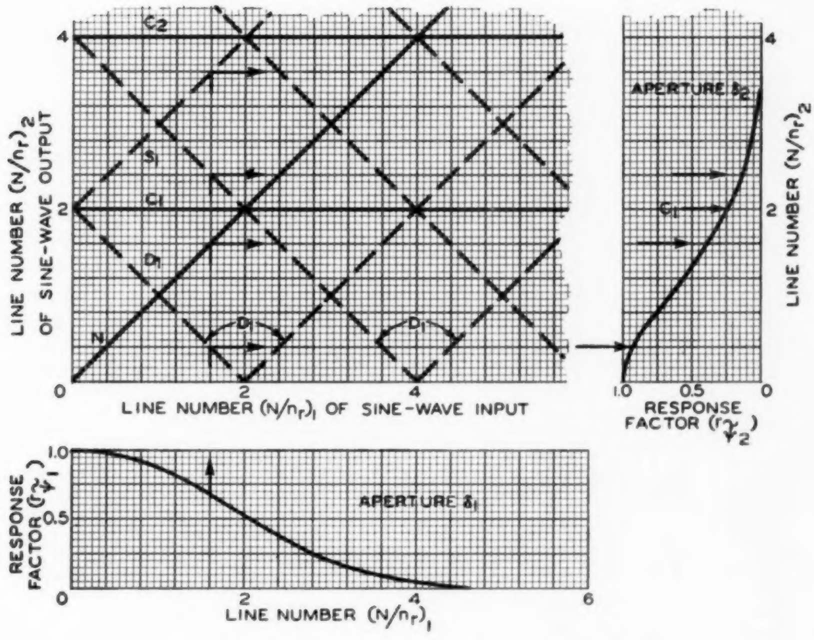


Fig. 70. Conversion characteristic of raster (Eq. (57)).

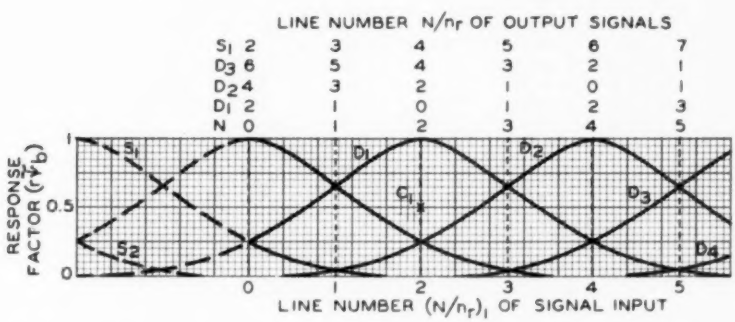


Fig. 71. Graphic representation of the combined sine-wave response of raster and synthesizing aperture δ_2 by normal aperture characteristic and "sidebands."

carrier components $2n_r$, $4n_r$ etc., and the "modulating" sine-wave signal N. Their magnitude and number depend on the response of both apertures δ_1 and δ_2.

The raster process introduces additional sine-wave components depending on the sine-wave response of the apertures δ_1 and δ_2. *The sine-wave response characteristic of the raster* itself can be represented graphically by a conversion characteristic (Fig. 70) with constant response factors $r_r = 1$ for all variable

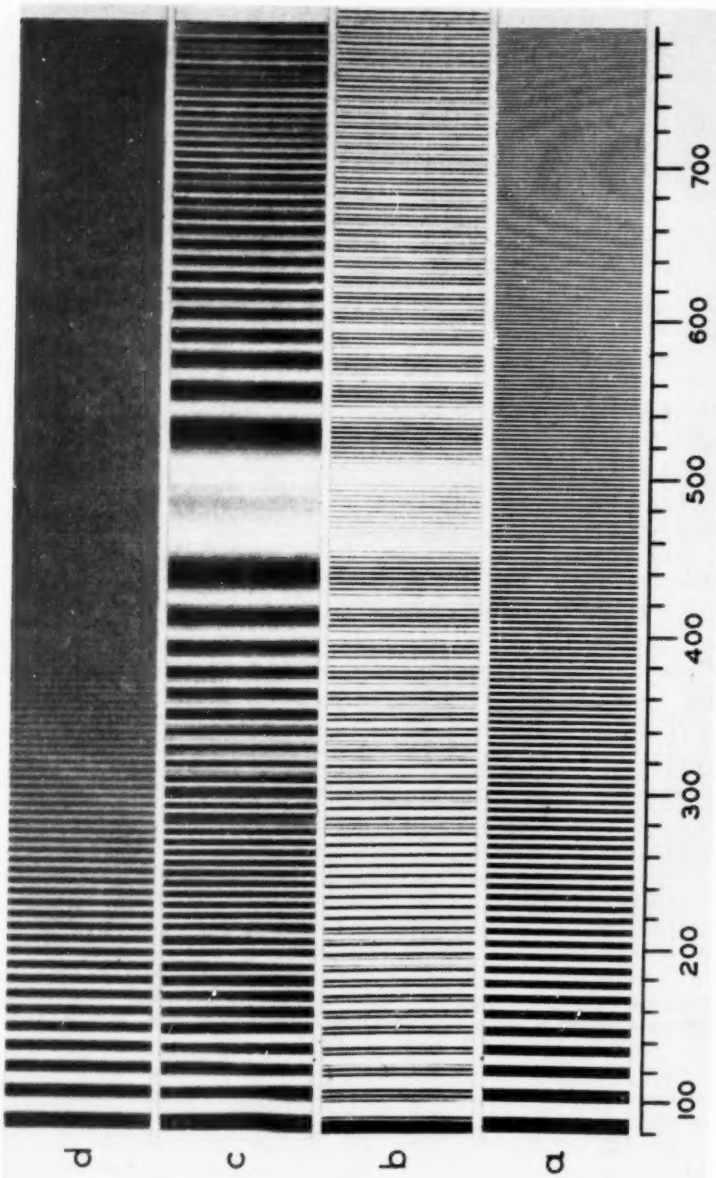


Fig. 72. Photographic proof of repeating line-number spectra ("side-bands") obtained by a line-raster process (see text).

Table XV. Sine-Wave Components $(N/n_r)_2$ and Response Factors (r_ψ) for $(N/n_r)_1 = 1.6$.

Component:	D_1	N	C_1	D_2	S_1	C_2
Line Number $(N/n_r)_2$	0.4	1.6	2	2.4	3.6	4
Response Factor $r_{\psi 1}$	0.675	0.675	0.675	0.675	0.675	0.675
Response Factor $r_{\psi 2}$	0.92	0.39	2 × 0.25	0.14	0.0	0.0
Overall Response Factor $r_{\psi y}$	0.62	0.263	0.338	0.945	0.0	0.0

terms and the response $r_r = 2$ for the constant carrier components. The carrier components are represented by an infinite number of horizontal lines C_1, C_2 etc., because their existence is independent of the sine-wave signal input. The line number of the normal sine-wave components (line N) and the sum and difference terms (lines $S_1, S_2, S_3 \ldots$ and $D_1, D_2, D_3 \ldots$), however, vary with the line number $(N/n_r)_1$ of the input-signal as shown by the network of diagonal raster characteristics. *The raster characteristic (Fig. 70) is a graphic representation of Eq. (57).* The use of the diagram is simple. A vertical projection of the input line number $(N/n_r)_1$ locates the output signal components at the intersections with the raster characteristics as illustrated for $(N/n_r)_1 = 1.6$. *The relative intensity of the sine-wave components* is the product of the aperture response factor $r_{\psi 1}$, at the line number of the input-signal and the response factor $r_{\psi 2}$ at the line number of the output-signal component. The sine-wave response characteristic of the "analyzing" aperture δ_1 is, therefore, drawn in Fig. 70 under the input coordinate of the raster characteristic, and the sine-wave response characteristic of the "synthesizing" aperture δ_2 is drawn with its line-number scale parallel to the output coordinate (both line-number scales must be in relative units N/n_r). The sine-wave response factors of the example are listed in Table XV for $(N/n_r)_1 = 1.6$.

To evaluate the total sine-wave spectrum of a raster process it is expedient to combine the raster response r_r with the response characteristic $r_{\psi b} = r_{\psi 2} r_{\psi 3} \ldots r_{\psi n}$ of succeeding apertures into one characteristic. The characteristic Fig. 71 represents the overall sine-wave response $r_{\psi rb}$ for constant amplitude sine-wave signals of the raster and a particular aperture process (δ_b) following the raster. Appropriate scales permit a direct reading of the line number and response factor $r_{\psi b}$ of all associated terms in the y-coordinate of the final image. The response factor $(2r_\psi)$ of the single constant carrier term C_1 is indicated. The normal response characteristic (N) of the aperture δ_b appears symmetrically repeated† at each carrier line number $2n_r$, $4n_r$ etc. The response pattern between $N/n_r = 0$ and 1 repeats indefinitely. A large aperture for example has zero response at $N/n_r < 1$; its response nevertheless repeats up to infinity, periodically going to zero.

The fact that the passband of an aperture δ_b is repeated by addition of a raster process, is demonstrated by Figs. 72a to 72d. Figure 72a is a photograph of a test pattern having a variable line number.[2] A sharp photograph (δ_b small) of the pattern through a raster plate having very fine lines (δ_a small) is shown in Fig. 72b. A photograph made with a larger aperture δ_b giving a flat field is shown in Fig. 72c which may be compared with the image Fig. 72d made without raster and the same aperture δ_b. In all practical cases the infinitely repetitive spectrum of the response $r_{\psi rb}$ is limited by the finite response $r_{\psi a}$ of apertures *preceding* the raster, because the overall

† Electrically known as "sidebands."

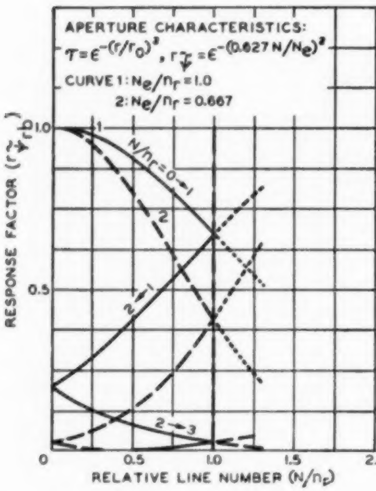


Fig. 73. Construction of repetitive spectrum by "folding" of response characteristic.

response of the entire imaging system $r\tilde{\psi}_{(y)} = r\tilde{\psi}_a r\tilde{\psi}_b r_r$ becomes zero when the response factor $r\tilde{\psi}_a$ is zero.

4. Sine-Wave Spectrum and Equivalent Passband $N_{e(s)y}$ for Random Deviations

For the analysis of deviations it is unnecessary to examine the waveform and phase distortion caused by the raster (to be discussed in Part IV of this paper), because the distribution of sine-wave components in a source of deviations is random. The sine-wave spectrum for deviations is, hence, obtained by arranging all sine-wave components in order of their line number, combining response factors at equal line numbers by a quadrature addition (square root of the sum of the squares). This process has been carried out for a variety of aperture combinations δ_a and δ_b having exponential cross sections $\tau = \epsilon^{-(r/r_0)^2}$ and a sine-wave response $r\tilde{\psi} = \epsilon^{-(0.627N/N_e)^2}$ (Fig. 44, Part II) which is a satisfactory equivalent for optical processes. The repetitive section of raster and aperture response characteristic $r\tilde{\psi}_{rb}$ can be constructed by "folding" the normal response characteristic into the range $N/n_r = 0$ to 1 as illustrated in Fig. 73 for two aperture sizes $N_e/n_r = 1$ and $N_e/n_r = 0.667$.

Overall sine-wave spectra computed for various combinations of aperture sizes are shown in Figs. 74a to 74c. When both apertures δ_a and δ_b are large, i.e., when N_e is smaller than the raster constant ($N_e/n_r = 0.5$ in Fig. 74a), the sine-wave spectrum is substantially the same as without raster; when $N_{e(b)}$ is increased, the high-"frequency" components increase considerably faster than without raster and show periodic maxima and minima. These variations decrease when $N_{e(a)}$ is increased (Fig. 74b), and disappear substantially for values $N_{e(a)} = 1$ (Fig. 74c). It is concluded that the addition of a raster process may increase the normal sine-wave response and extend the aperture passband to higher line numbers even for the "flat-field" condition $N_{e(a)} = N_{e(b)} = 0.67\,n_r$ (Fig. 74b). The raster can, therefore, have a substantial *negative aperture effect* which increases the intensity and edge sharpness of the reproduced grain structure in the *y*-coordinate.

The equivalent passband $N_{e(s)v}$ *of the raster process* is the integral of squared response factors (Eq. (28), Part II) determined from the total sine-wave response of the system. The computation of the integral for various aperture combinations can be simplified by calculating the *rms response* of δ_b for the repetitive section $N/n_r = 0$ to 1. The rms response factor $[r\tilde{\psi}]_b$ at each input line number (Fig. 75) is obtained by a quadrature addition of associated sine-wave components (shown in Fig. 73). Because this response is repetitive, the integral

$$N_e = \int_0^\infty ([r\tilde{\psi}]_b r\tilde{\psi}_a)^2{}_{N/n_r} d(N/n_r)$$

can be evaluated within the limits $N/n_r = 0$ and 1 from

$$N_{e(s)v} = \int_0^{N/n_r=1} ([r\tilde{\psi}]_b [r\tilde{\psi}]_a)^2{}_{(N/n_r)} d(N/n_r) \tag{58}$$

where $[r\tilde{\psi}]_a$ is the rms value of response factors of δ_a, coordinated by folding the

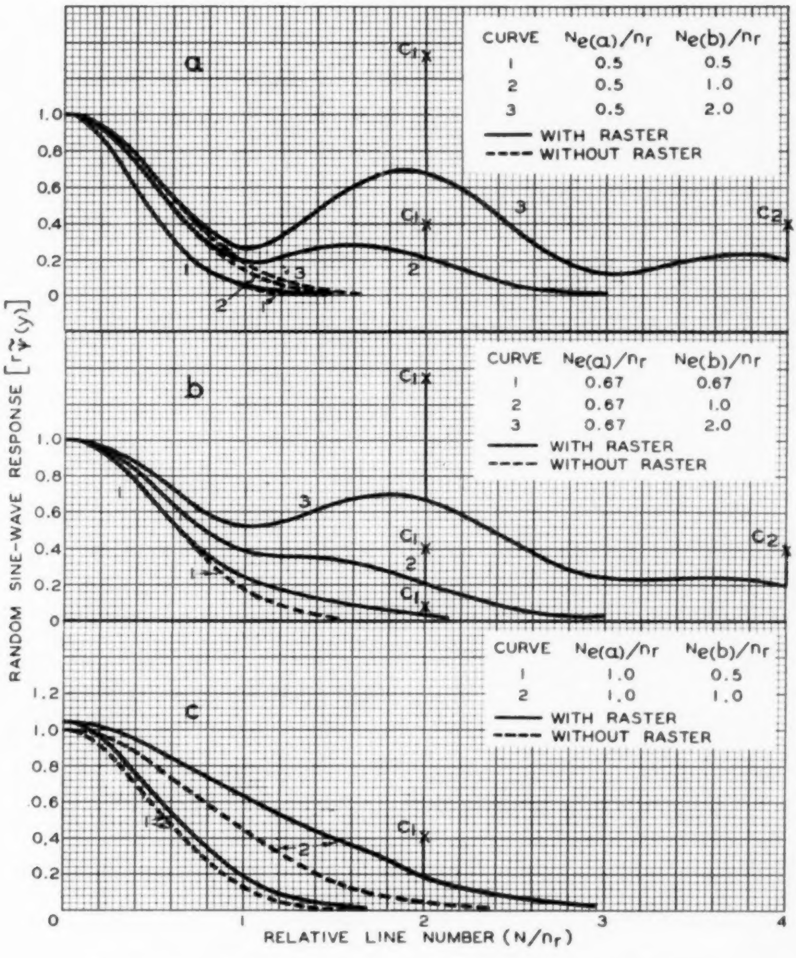


Fig. 74. Overall sine-wave spectra of raster processes for various aperture sizes δ_a and δ_b.

response characteristic $r\psi_a$ into the limits $N/n_r = 0$ to 1. The values $[r\psi]_a$ and $[r\psi]_b$ are identical when $\delta_a = \delta_b$. The products of various aperture combinations are, thus, easily computed from Fig. 75. The equivalent passbands $N_{e(a)v}$ of the system are plotted in Fig. 76 as a function of the passband $N_{e(a)}/n_r$ of the analyzing aperture δ_a with $N_{e(b)}/n_r$ as a parameter. Examination of these functions reveals the following facts.

(*a*) *When both $N_{e(a)}$ and $N_{e(b)}$ are smaller than $0.7n_r$* the aperture flux at successive raster points is correlated sufficiently (overlapping) to eliminate the effect of the raster. The equivalent passband

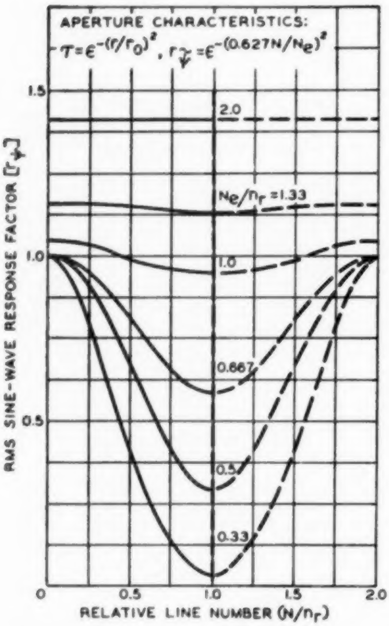


Fig. 75. Rms response of apertures and raster to sine-wave signals.

$N_{e(s)v}$ of the process can then be computed from the normal aperture response without raster or may be approximated with good accuracy by the cascade formula:

$$1/N_{e(s)v} = (1/N_{e(a)}^2 + 1/N_{e(b)}^2)^{\frac{1}{2}} \quad (59)$$

(*b*) *When one or both values $N_{e(a)}$ or $N_{e(b)}$ are greater than n_r*, the aperture flux is no longer correlated by at least one aperture, and the equivalent passband of the process can be computed with good accuracy from the product.

$$N_{e(s)v} \simeq (N_{e(a)} N_{e(b)})/n_r \quad (60)$$

(*c*) *For all other values* the aperture flux is partially correlated and the value $N_{e(s)v}$ should be computed as outlined above or may be approximated by the values computed for exponential aperture characteristics (Fig. 76). It should be mentioned that a square aperture presents a special case because of its strongly periodic aperture response and large number of terms which cause periodic deviations from the characteristics shown in Fig. 76. The square aperture is of interest as a mathematical equivalent, but its characteristics are in many cases undesirable for practical processes. The greatly enlarged reproduction of a photographic grain structure by point- and line-raster processes is illustrated in Fig. 77. The original grain structure is shown in Fig. 77a. The samples "seen" through a fine point raster plate (δ_a small) are shown in Fig. 77b; their reproduction by a square aperture providing a "flat" field is shown in Fig. 77c. Reproduction of the same grain structure by a line-raster process using a square reproducing aperture is shown in Figs. 77d and e. The higher horizontal definition obtained with a vertical slit aperture is illustrated by Fig. 77f.

A comparison of a line-raster process (a) using a round $\cos^2$ aperture δ_b with a continuous process (b) using the same apertures is shown with a lower magnification in Fig. 78. The slight increase in vertical sharpness by the raster process (a) observed in the originals will probably be lost in the printing process.

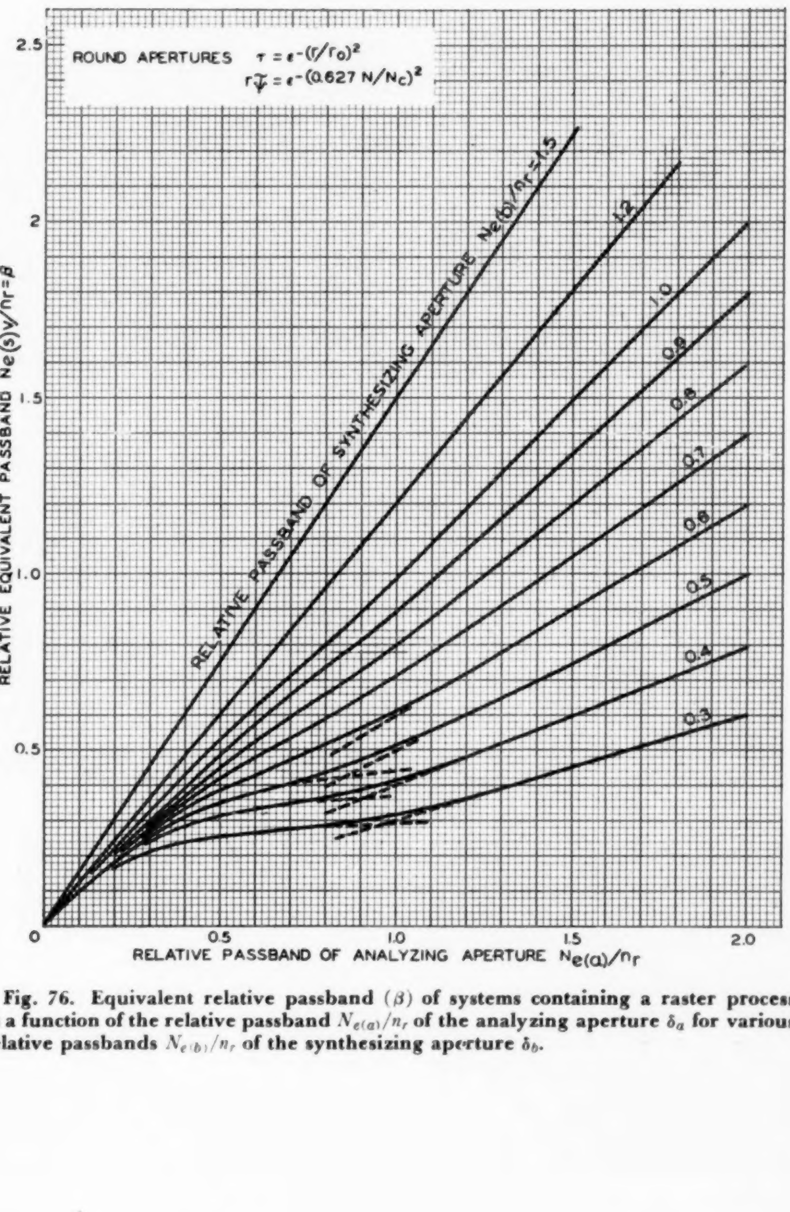


Fig. 76. Equivalent relative passband (β) of systems containing a raster process as a function of the relative passband $N_{e(a)}/n_r$ of the analyzing aperture δ_a for various relative passbands $N_{e(b)}/n_r$ of the synthesizing aperture δ_b.

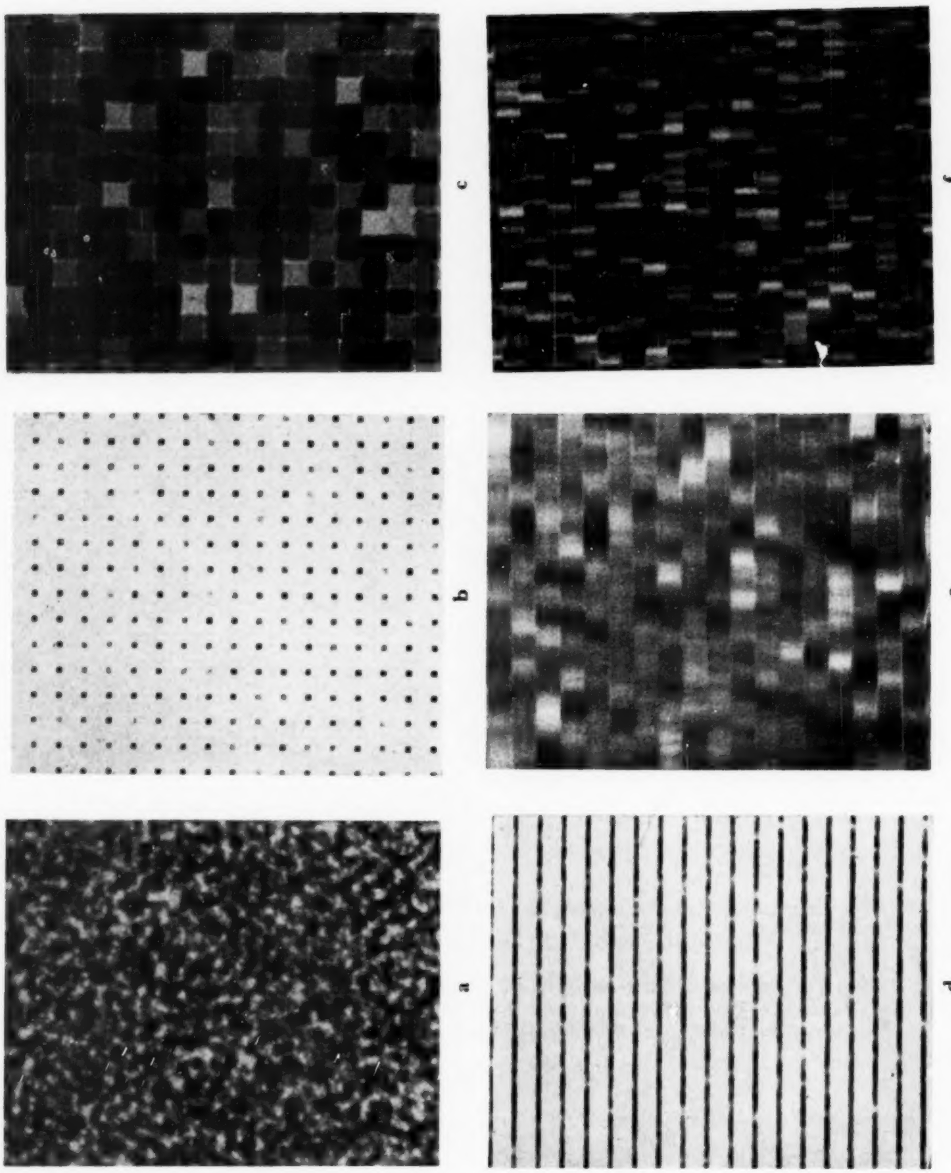


Fig. 77. Reproduction of photographic grain structure by point- and line-raster processes with rectangular apertures (highly magnified).

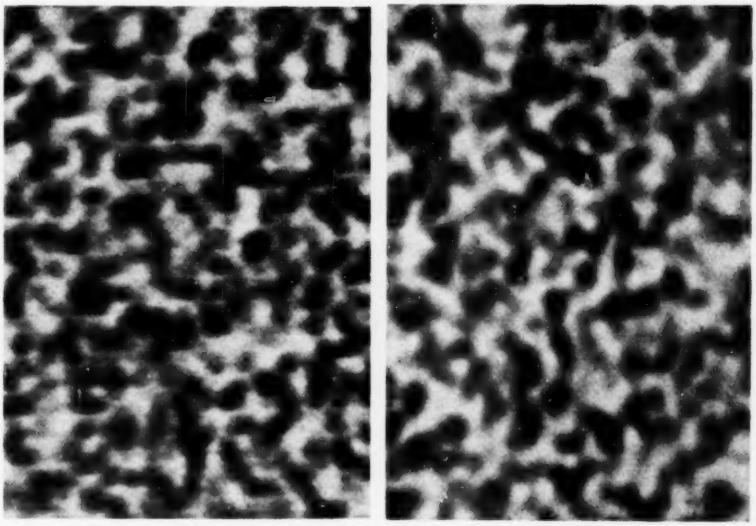


Fig. 78. Grain structure reproduced (a, at left) with, and (b, at right) without line-raster process by a round cos² aperture.

NOTE: Figures 85 and 109 now follow on this coated paper insert. Figures 79, etc., are arranged below as best possible for nearness to pertinent text.

C. ELECTRICAL CONSTANTS AND APERTURES OF TELEVISION SYSTEMS

1. Frequency and Line Number

The transmission of two-dimensional images over an electrical frequency channel is based on a conversion of lengths into units of time. To effect this conversion, television systems make use of a horizontal-line raster scanned by a single aperture. The signals of all aperture positions in the raster are transmitted in sequence because of a time-proportional displacement of the aperture along the raster lines. The correlation of length and time units depend obviously on the dimensions of the raster, the order in which the raster lines are scanned, and the time T_f assigned for the transmission of one picture frame. The principal relations are illustrated in Fig. 79 for a raster constant $n_r = 12$ and the normal frame aspect ratio $H/V = 4/3$. A time allowance must be made for synchronizing signals and the finite return periods of the scanning apertures. These time percentages are the "blanking" periods t_{b_v} and t_{b_h} in Figs. 79b and c which correspond to the blanking margins b_h and b_v in Fig. 79a.

The length unit l is the vertical frame dimension V, as indicated in Fig. 79a. In the vertical coordinate the length l or any subdivision down to $\Delta l = 1/N_v = 1/n_r$ corresponds to relatively long time intervals, i.e., low electrical frequencies.

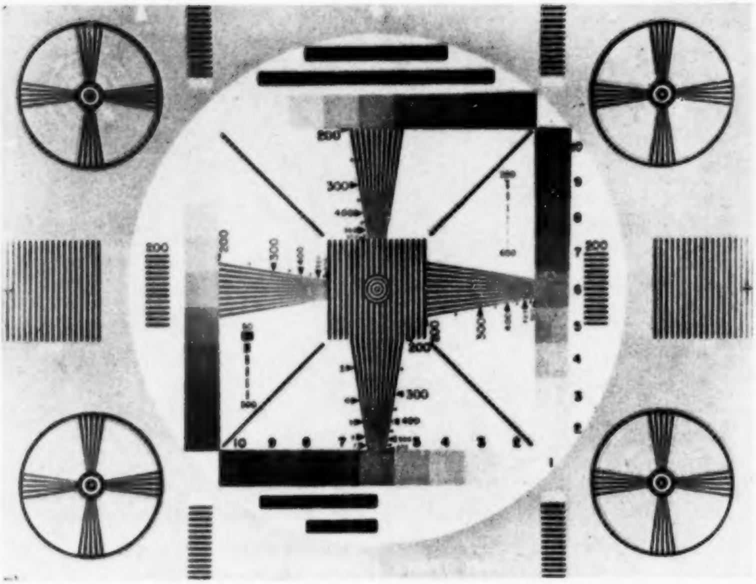


Fig. 85a. Composite print made by a photographic synthesis (Fig. 84).

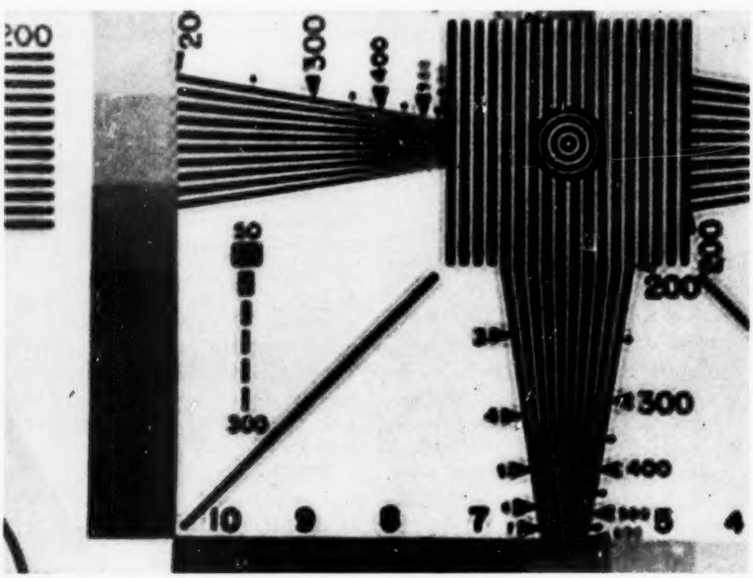


Fig. 85b. Enlarged section of Fig. 85a showing edge "transients" in two coordinates.

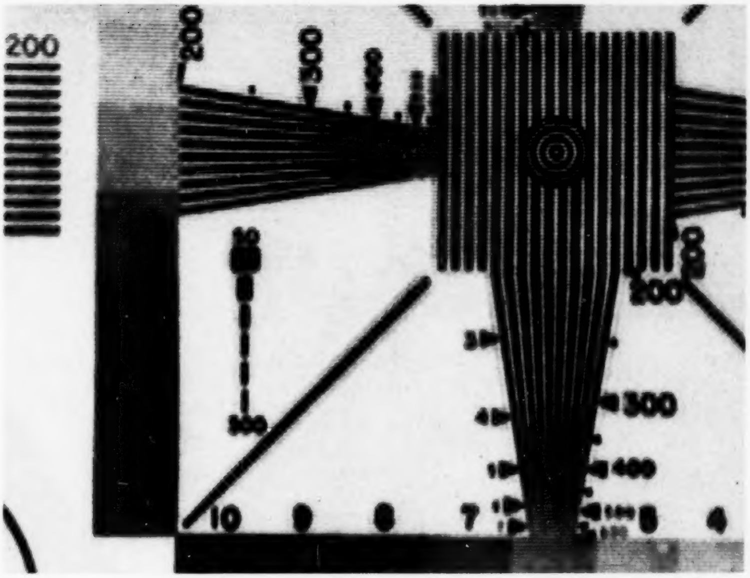


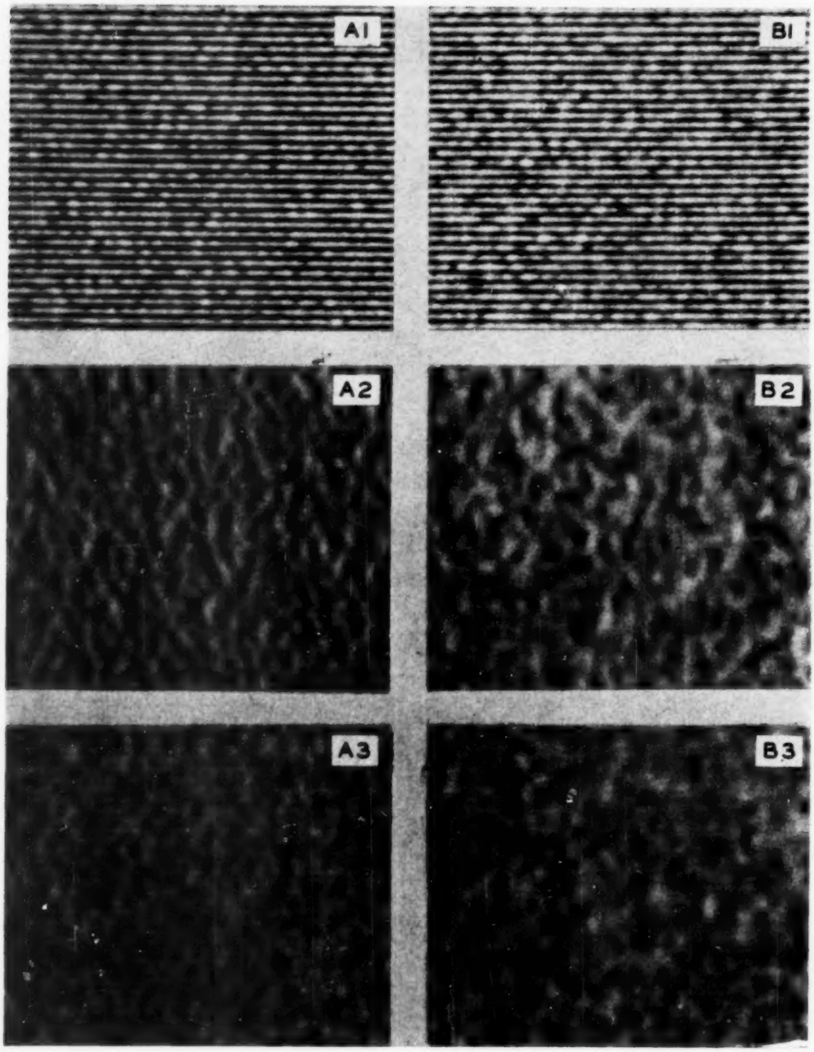
Fig. 85c. Addition of optical line-raster process to Fig. 85b.

A test pattern with $N_v = 2$ (right side of Fig. 79a) filling the entire frame area generates the video signal illustrated in Fig. 79b. The electrical frequencies f_v required for the reproduction of vertical sine-wave samples N_v are determined by the raster constant n_r. The highest electrical frequency $f_{v\,max}$ is generated when the signal amplitudes in *successively traced*† raster lines alternate between two values. One period is, therefore, completed in the time $2t_h = 2T_f/n_r$ (see Fig. 79b).

In all properly operating television systems the electrical sine-wave response is unity and is without phase error from the frame frequency $(1/T_f)$ on upwards to far beyond the frequencies occurring in the reproduction of vertical sine-wave samples. The sine-wave response, therefore, does not enter as a factor limiting the vertical sine-wave response of the television system. *The vertical response of the television system* is determined entirely by the raster constant n_r and the two-dimensional system apertures as described in the preceding section.

In the horizontal coordinate the length unit $l = V = 3/4H$ (see Fig. 79c) and the length of half-waves l/N_h in a sine-wave test pattern are scanned in very short time intervals t_{N_h} corresponding to high electrical frequencies. The spatial frequency of the optical test pattern wave has the value $0.5N_h/l$. The horizontal time unit is three fourths of the active line time, and the electrical frequency corresponding to a line number N_h is therefore:

† It is noted that successively traced raster lines in a 2 to 1 interlaced raster are either the even or the odd numbered raster lines which correspond to a test pattern line number $n_r/2$. Without interlacing, the frequency f_v max has the same value but the test pattern line number producing it is equal to n_r. With 2 to 1 interlace, a line number equal to n_r causes constant amplitude signals in one complete field and constant signals of different amplitude in the following field.



$$f_h = 0.5c\, N_h n_r / T_f \text{ cycles/sec} \quad (61)$$

where

T_f = Frame time in seconds ($\frac{1}{30}$ sec in standard television system)

n_r = Number of active raster lines in frame area

N_h = Horizontal line number

c = $(H/V)/(1 - b_h)(1 - b_v)$; the standard value is $c = (4/3)/(0.84 \times 0.935) = 1.7$

The total number of scanning lines including the inactive lines in the blanking margin b_v is usually stated as the scanning line number of the system, which is

$$n_s = n_r/(1 - b_v) = 1.07\, n_r \quad (62)$$

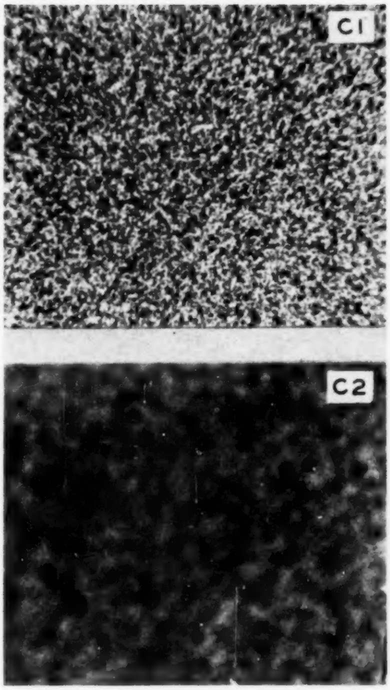


Fig. 109, A1–3 and B1–3 at left, and C1 and C2 above. Grain structures of television and motion-picture processes.

2. Theoretical Passband and Aperture (δ_f) of Television Systems

The video frequency channel of the television system is determined by the frame time T_f, the raster constant n_r, and the desired horizontal cutoff resolution $N_{e(h)}$ of the system; it is given for normal blanking percentages by the relation

$$\Delta f = 0.85\ N_{e(h)} n_r / T_f \text{ cycles/sec} \quad (63)$$

The product $(N_{e(h)} n_r)$ corresponds to the square of the equivalent passband $\bar{N}_e^2 = (N_{e(h)} N_{e(v)})$ of an optical aperture. The relation between the theoretical passband Δf of a television channel and its optical equivalent $\bar{N}_{e(f)}$ is, therefore:

$$\bar{N}_{e(f)} = (N_{e(h)} n_r)^{\frac{1}{2}} = K(\Delta f)^{\frac{1}{2}} \quad (64)$$

For normal blanking percentages the proportionality factor has the value $K = (T_f/0.85)^{\frac{1}{2}}$. The product $(N_{e(h)} n_r)$ has the dimension (length)$^{-2}$, and its reciprocal represents a rectangular area of uniform transmittance which may be regarded as an *equivalent point image or sampling aperture of a theoretical television channel.* This equivalent sampling aperture is often referred to as a "picture-element." The term is misleading because the concept of an element implies an invariable intensity distribution in a small area of fixed size. A process which is continuous in one coordinate forms an infinite number of point images and its true "elemental" area is infinitesimal. Only a point raster process can produce an elemental area of finite size.

The concepts of a *two-dimensional aperture δ_f having the exact response characteristic of a theoretical television channel* is useful for an interpretation of electrical random fluctuations (noise) in terms of optical deviations.

Electrical signal-to-noise ratios are usually computed for a given passband Δf having a theoretically sharp cutoff. This evaluation is analogous to the process of sampling a two-dimensional grain structure with a measuring aperture $\delta_m = \delta_f$ of known geometry to determine a reference value $[R]_m$ for the particular random structure (see Part II D). The sources of electrical random fluctuations in a television system (see Fig. 65) can, therefore, be replaced by random particle structures scanned by a hypothetical television camera. The scanning aperture of this camera is infinitesimal and

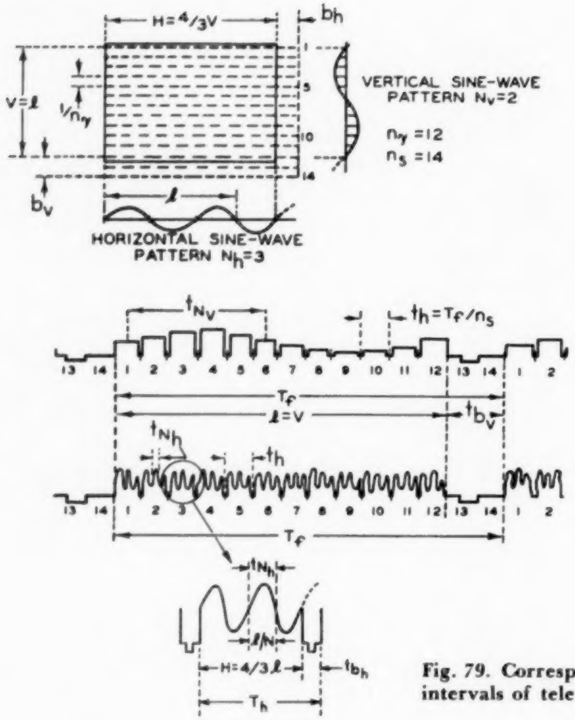


Fig. 79. Corresponding lengths and time intervals of television frame and signals.

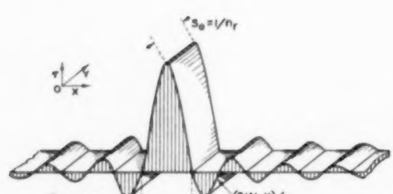


Fig. 80. Equivalent point image or sampling aperture of theoretical television channel.

its output signals are modified by the equivalent passband $\bar{N}_{e(s)}$ of the system elements following the "noise" source. The granularity (noise level) of the structure is computed by assuming that it is scanned with a measuring aperture $\delta_m = \delta_f$ which must fill the requirements that its signals are indistinguishable from electrical fluctuations in the corresponding theoretical channel Δf. The horizontal sine-wave response of δ_f is, therefore, constant in the passband $N_{e(h)} = N_{c(h)}$, its equivalent vertical passband is $N_{e(v)} = n_r$, and the aperture signals in different raster lines are uncorrelated.

The frequency spectrum of δ_f in the vertical coordinate may be determined as follows: it is assumed for simplicity that no interlacing is used. A vertical cross section in the frame area corresponds to a series of amplitude samples taken from the electrical aperture signal at the line intervals t_h (see Fig. 79). The sampling of constant electrical sine-wave signals by the raster process results in a series of constant sample amplitudes ($N_v = 0$) for

all frequencies which are integral multiples of the line frequency $f_h = 1/t_h$. When the signal frequency is changed by an increment $\Delta' f = f_h/2$, the sample amplitudes alternate between two fixed values at a frequency corresponding to the line number $N_v = n_r$. Frequency increments $\Delta' f$ between $\Delta' f = 0$ and $\Delta' f = f_h/2$ as well as between $\Delta' f = f_h$ and $\Delta' f = f_h/2$ cause a sequence of sample amplitudes identical with those obtained with an aperture sampling optical sine-wave patterns with line numbers from $N_v = 0$ to $N_v = n_r$. The amplitudes of the electrically taken samples vary according to the phase relation between sampling points and sine-wave signal, just as aperture samples depend in magnitude on the relative phase between the raster lines and the optical sine-wave pattern. The electrical samples can, therefore, be attributed to a hypothetical aperture δ_f scanning sine-wave patterns with a line number range $N_v = 0$ to $N_v = n_r$. This range of line numbers is sampled repetitively throughout the video frequency band in every increment $\Delta' f = f_h/2$. Because the electrical response within any one of these small sections of the video passband is substantially constant, the rms values of the aperture signals at any one line number $N_v = 0$ to n_r from all sections $\Delta' f$ are alike. The vertical sine-wave response of δ_f is constant between $N = 0$ and $N = n_r$ and independent of the horizontal response characteristic of the video system.

The raster characteristic (Fig. 70) transforms this limited constant amplitude spectrum into an infinite frequency spectrum (see section B4) which is subsequently limited by the real aperture δ_b following the raster process, and results in an overall response identical with the response characteristic of δ_b. *An electrical "noise" source followed by a "flat" video channel Δf with theoretical rectangular cutoff can, therefore, be replaced by a random particle structure scanned by an aperture δ_f having constant sine-wave response in both x- and y-coordinates within the range of line numbers $N_{c(h)}$ and n_r respectively.* The equivalent passband of this hypothetical scanning aperture is $\bar{N}_{e(f)} = (N_{c(h)} n_r)^{\frac{1}{2}}$ as stated by Eq. (64).

It is of interest to determine the geometric characteristics of this aperture. A harmonic synthesis of the horizontal aperture cross section from its response characteristic (see Eq. 54) shows that the *transmittance* τ_h varies as a $(\sin x)/x$ function (Fig. 80) and has positive and negative portions decaying slowly to zero at infinity.† The central peak between the first zero points has a dimension $\delta_0 = 2/N_{c(h)}$. The aperture transmittance τ_v in the vertical coordinate (y) can be given a rectangular shape with constant transmittance $\tau_v = 1$ and a width $s_0 = 1/n_r$. This dimension meets the requirements $N_{c(v)} = n_r$ and that signals in different scanning lines be uncorrelated. The continuous sine-wave response (in y) of this rectangular aperture has a $(\sin x)/x$ form with a first zero at $N_v = 2n_r$. In conjunction with the raster characteristic, however, the $(\sin x)/x$ response produces a frequency spectrum identical with that from a constant aperture response in the range $N/n_r = 0$ to 1. The $(\sin x)/x$ response "folded" into this range results in unity rms response factors when the response factors of all input frequencies giving the same output frequency, are combined.

3. Horizontal Sine-Wave Response and Aperture Characteristics of Electrooptical Systems

(*a*) *General Formulation.* The principal elements determining the horizontal response characteristic of a television system are indicated in the block diagram Fig. 65. The horizontal sine-wave response of television systems can be made very dissimilar to that of optical systems by adjustment of the response

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† An optical synthesis of images with apertures containing negative flux components is discussed in the following section.

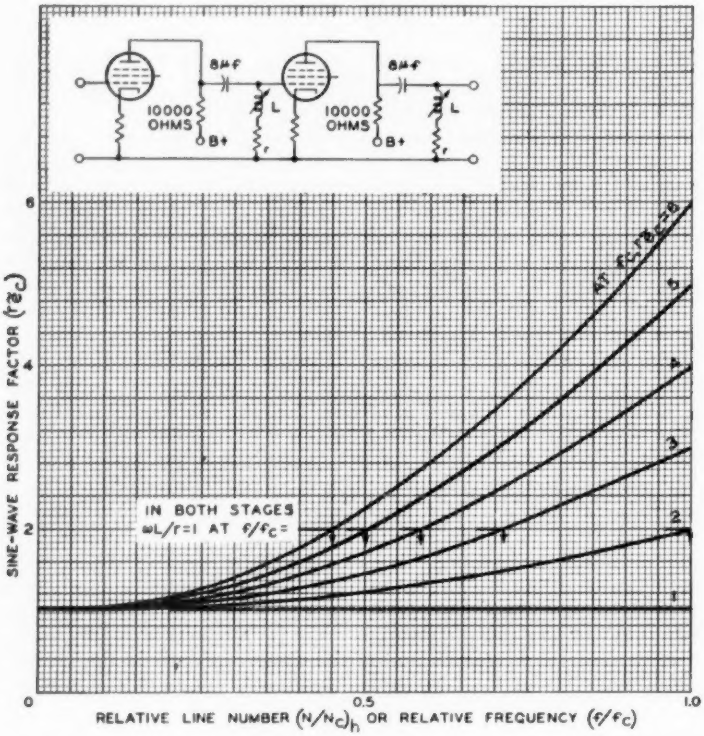


Fig. 81. Aperture correction circuit and response characteristics.

characteristic $r_{\mathfrak{z}}$ of the video system. The response of amplifiers and filter circuits is normally constant within a substantial portion of their passband but can also be given a rising characteristic by corrective networks. The sine-wave response $r_{\mathfrak{z}c}$ of a two-stage amplifier circuit for correcting the sine-wave response of camera tubes is shown in Fig. 81. A phase-correcting circuit is used in conjunction with the amplitude-correcting circuits. Electrical networks of this type are termed *aperture-correction circuits* because they can completely or partially compensate the decreasing horizontal response $r_{\psi h}$ of two-dimensional apertures. The horizontal response of an electrooptical system is given in general by

$$r_{\psi(s)h} = (r_{\mathfrak{z}} r_{\psi})_{(N/N_c)h} \qquad (65)$$

where

$r_{\mathfrak{z}}$ = $(r_{\mathfrak{z}12} r_{\mathfrak{z}c} r_{\mathfrak{z}f})_{(f/f_c)}$ = overall electrical response characteristics

$r_{\mathfrak{z}12}$ = $r_{\mathfrak{z}1} r_{\mathfrak{z}2}$ = response of preamplifier ($r_{\mathfrak{z}12} = 1$ for an equalized preamplifier, see discussion in 3(*c*)

$r_{\mathfrak{z}c}$ = response factor of aperture correction circuits (Fig. 81)

$r_{\mathfrak{z}f}$ = response factor of low-pass filter (Fig. 82)

$N_{c(h)}$ = horizontal cutoff resolution (Eq. 63))

r_{ψ} = $(r_{\psi(a)} r_{\psi(b)})_{(N/N_c)h}$ = response characteristic of all two-dimensional system apertures.

(*b*) *Apertures and Aperture Effects of Electrical Elements.* An aperture correction $r_{\mathfrak{z}c} = 1/r_{\psi}$ results in a system response equal to that of the cutoff filter:

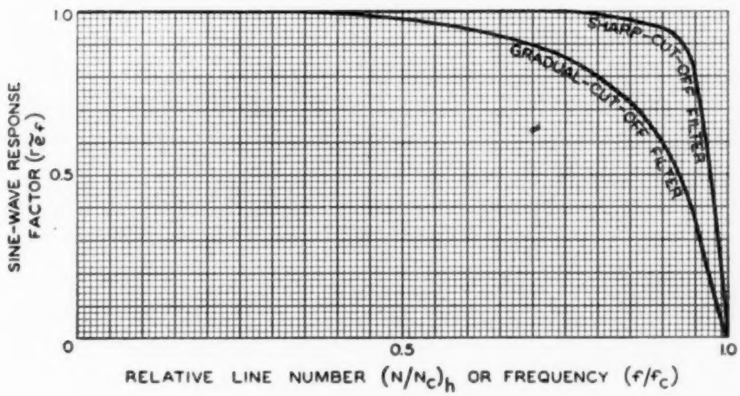


Fig. 82. Sine-wave response of electrical low-pass filters.

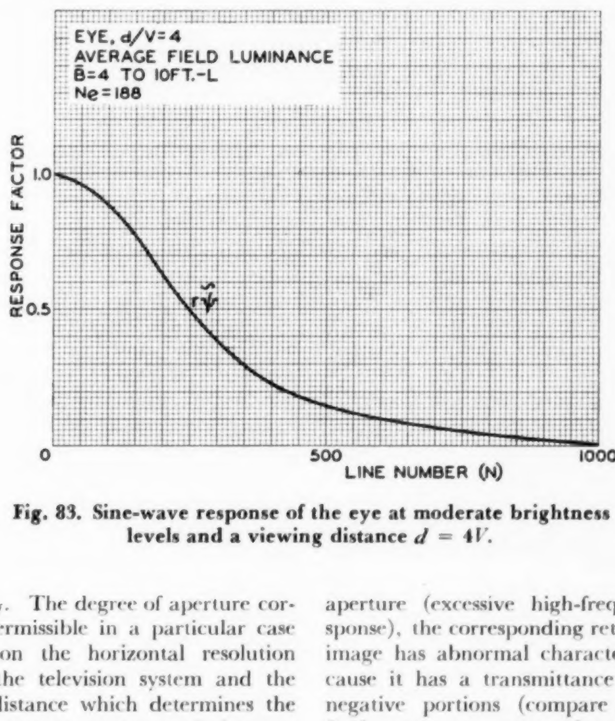


Fig. 83. Sine-wave response of the eye at moderate brightness levels and a viewing distance $d = 4V$.

$r\tilde{\psi}_{(s)} = r\tilde{z}_f$. The degree of aperture correction permissible in a particular case depends on the horizontal resolution $N_{c(h)}$ of the television system and the viewing distance which determines the relative aperture response of the eye. When the cascaded response characteristic $r\tilde{\psi}_{(s)}r\tilde{\psi}_{eye}$, *including the visual system,* departs markedly from that of an optical aperture (excessive high-frequency response), the corresponding retinal point-image has abnormal characteristics because it has a transmittance (τ_s) with negative portions (compare Fig. 80). Such apertures cause edge transitions distorted by "transient" overshoots or oscillations, and result in a relief effect or multiple contour lines. It is not difficult

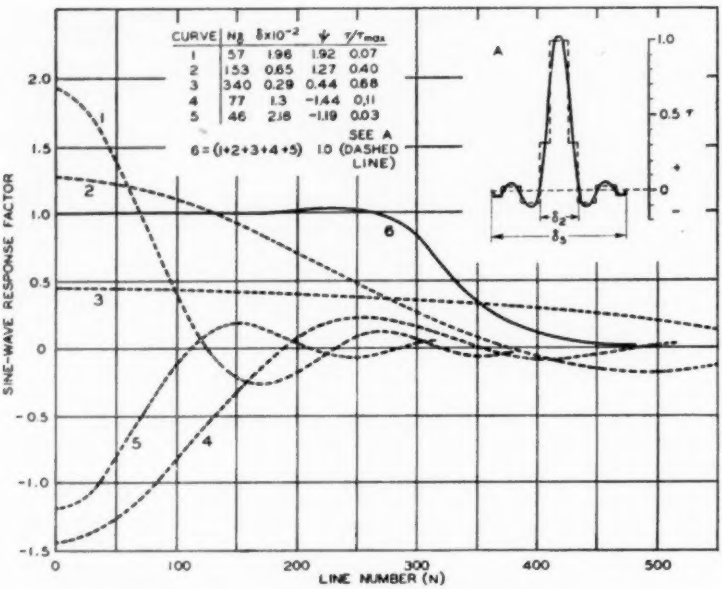


Fig. 84. Synthesis of a "flat"-response characteristic with sharp cutoff by addition of 3 positive- and 2 negative-response characteristics of round apertures with uniform transmittance.

to see that a system response $r\psi_{(s)}$ extending beyond two-thirds of the passband of the eye (see Fig. 83) can be given a constant value with sharp cutoff without causing an abnormal overall response in the retinal image. When the cutoff of the television system, however, occurs in the lower half of the visual passband, due to low system resolution or close viewing distances, aperture correction must be limited to a system response $r\psi_{(s)}$ having more gradual cutoff, to prevent abnormal optical conditions in the retinal image.†

The effects of apertures having negative transmittance can be demonstrated by a photographic correction process. The response characteristic (6) of the point image shown in Fig. 84, for example, can be synthesized by superimposition of three positive and two negative components. Images can be synthesized by two sets of out-of-focus projections with appropriate lens stops. The positive-aperture effects are combined in one plate by a triple exposure. The negative-aperture plate is made by a double exposure with positive apertures and reversed in polarity in a contact print. A composite print from the positive and negative plates in register is shown in Figs. 85a and b and illustrates the transients and sharp cutoff (in both image coordinates) produced by the response

† This subject will be discussed further in Part IV.

Figures 85a, 85b and 85c are on plate pages 116 and 117.

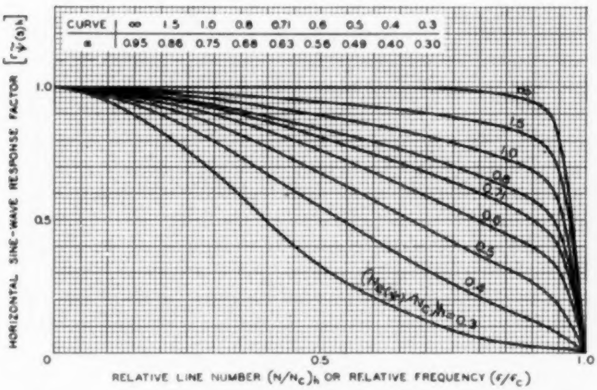


Fig. 86a. Normalized response characteristics for "flat" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 1 × aperture correction (Fig. 81).

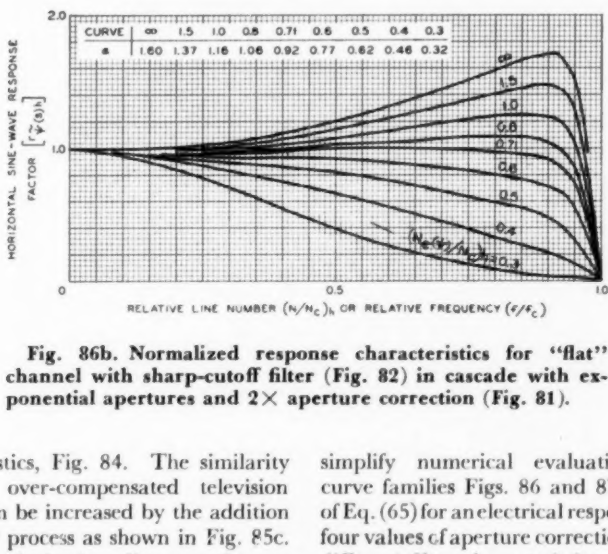


Fig. 86b. Normalized response characteristics for "flat" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 2 × aperture correction (Fig. 81).

characteristics, Fig. 84. The similarity with an over-compensated television process can be increased by the addition of a raster process as shown in Fig. 85c. At increased viewing distances the undesirable transients disappear, because the overall response is then given a normal shape by the eye characteristic.

(c) Generalized Response and Aperture Characteristics. The sine-wave response characteristics of electrooptical systems have been computed in normalized units as a function of system parameters to simplify numerical evaluation. The curve families Figs. 86 and 87 are plots of Eq. (65) for an electrical response r_{ξ} with four values of aperture correction and two different filter characteristics, in cascade with various optical apertures. The cascaded response of all two-dimensional apertures in the system under consideration is closely approximated by the response characteristic $r_{(\psi)}$ of one equivalent exponential aperture (Fig. 44 and Table VII, Part II). The parameter $(N_{e(\psi)}/N_c)_h$ specifies the equivalent pass-

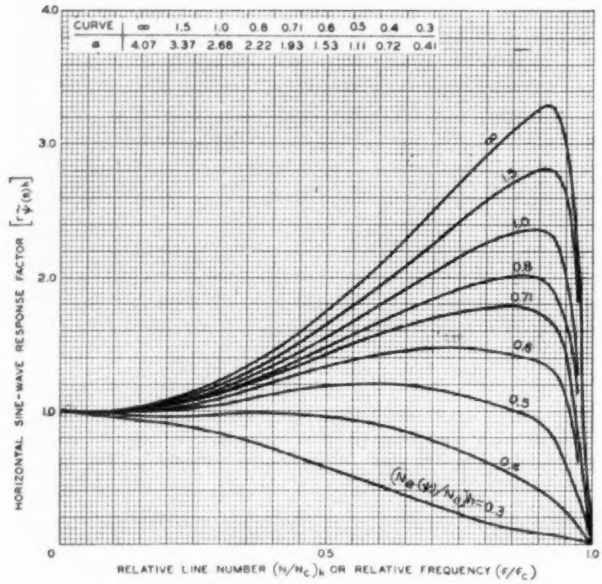


Fig. 86c. Normalized response characteristics for "flat" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 4× aperture correction (Fig. 81).

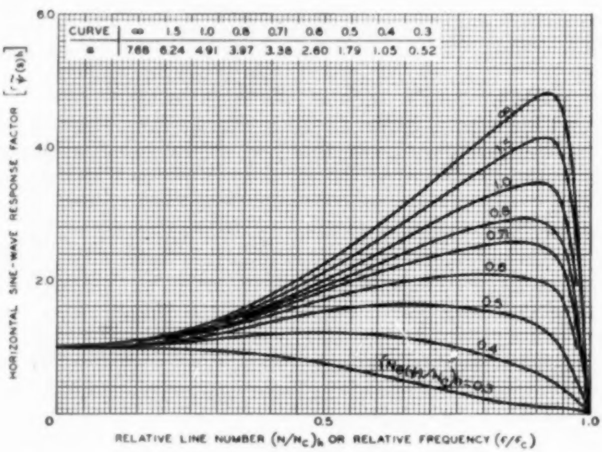


Fig. 86d. Normalized response characteristics for "flat" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 6× aperture correction (Fig. 81).

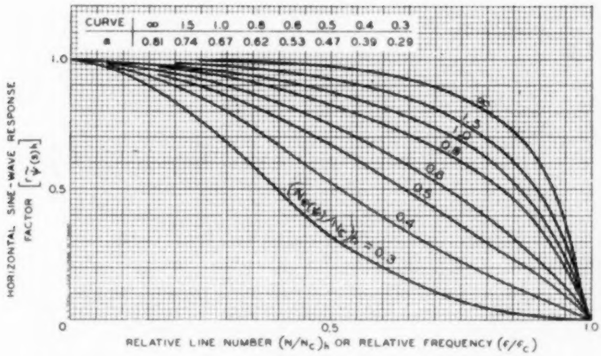


Fig. 87a. Normalized response characteristics for "flat" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 1× aperture correction (Fig. 81).

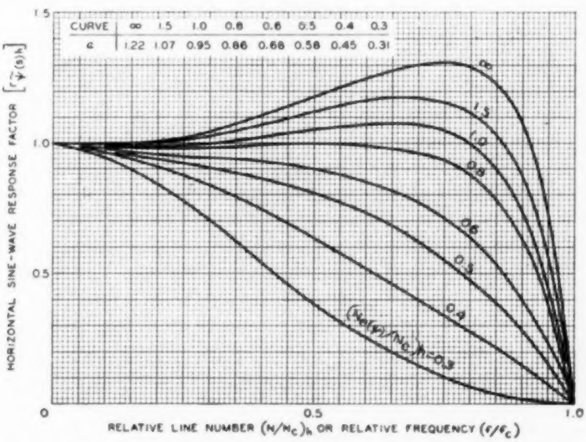


Fig. 87b. Normalized response characteristics for "flat" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 2× aperture correction (Fig. 81).

band of this aperture relative to the theoretical bandwidth $N_{c(h)}$ of the electrical system. The equivalent passband $N_{e(s)h}$ of the response characteristics is specified likewise in relative units by the ratio $\alpha = (N_{e(s)}/N_c)_h$ defined as the *bandwidth factor* in section D1.

If the system is considered as a purely electrical network, the *aperture transmittance* τ_h *of the system* is its response to a single impulse of infinitesimal duration. The optical equivalent is the response of the electrooptical system to isolated lines of infinitesimal width. The impulse shapes or aperture cross sections (transmittance τ_h) corresponding to the response characteristics Figs. 86 and 87 have been computed by a Fourier synthesis (Eq. (54)) which is valid for the condition of zero phase shift or a linear

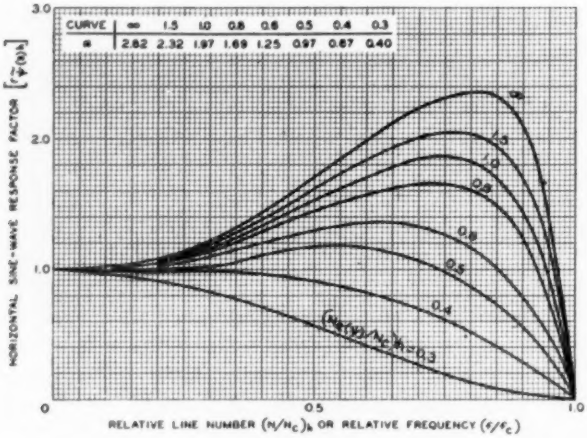


Fig. 87c. Normalized response characteristics for "flat" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 4× aperture correction (Fig. 81).

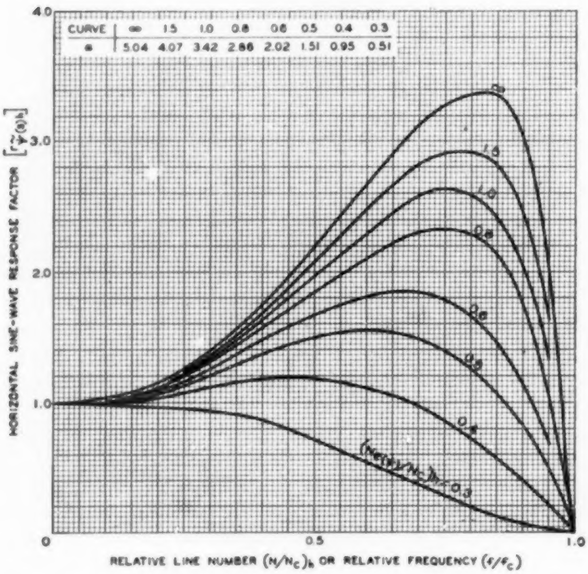


Fig. 87d. Normalized response characteristics for "flat" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 6× aperture correction (Fig. 81).

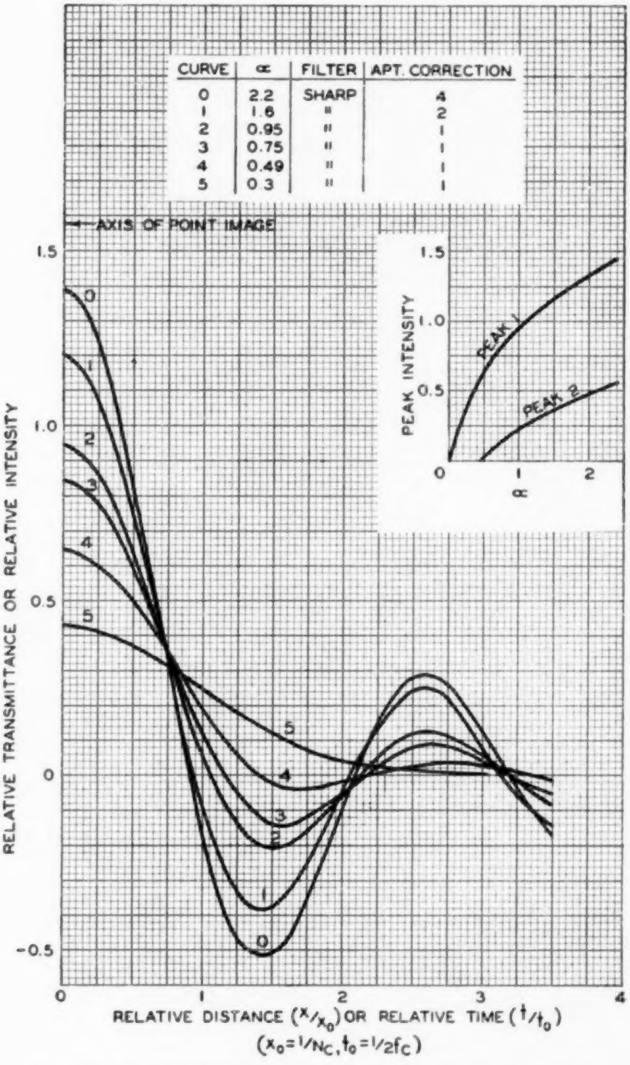


Fig. 88. Impulse forms or aperture transmittance obtained with response characteristics Figs. 86 and 87.

phase delay within the system passband. The aperture cross section (τ_A) depends, again, on the relative equivalent passband (α) as shown in Fig. 88.

Phase distortion between sine-wave components can occur in electrical and also in optical elements (lenses, etc.). In terms of aperture properties it is caused by an asymmetric aperture transmittance (coma for example) and results

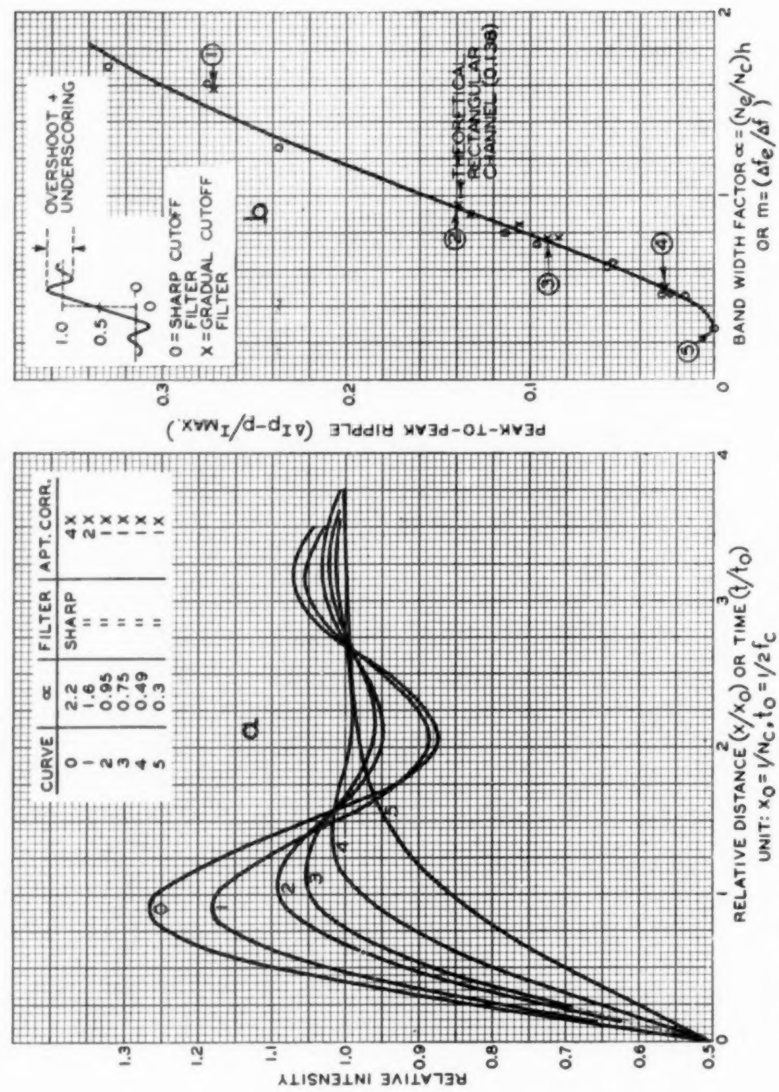


Fig. 89. Edge transitions and transient ripple obtained with response characteristics Figs. 86 and 87.

in asymmetric edge transitions. Phase distortion is of little importance in the transfer of random deviations, but it is an important aperture property determining waveform distortion. The measurement and effects of phase distortion will be discussed with the subjects of image sharpness and definition in Part IV of this paper.

The electrical response to a step function, or the corresponding electrooptical response to a sharp edge, is obtained by integration of

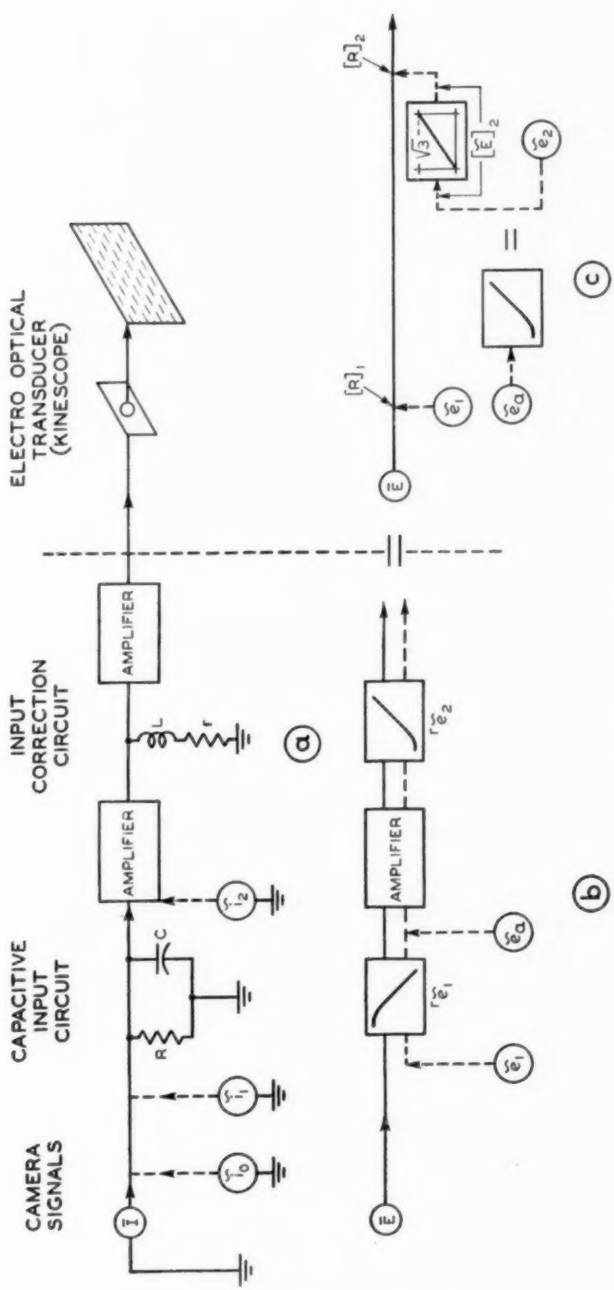


Fig. 90. Camera circuits and noise sources.

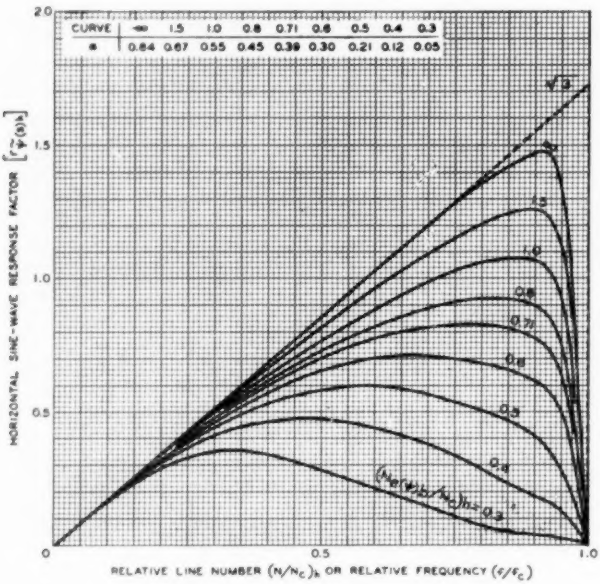


Fig. 91a. Normalized response characteristic for "peaked" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 1× aperture correction (Fig. 81).

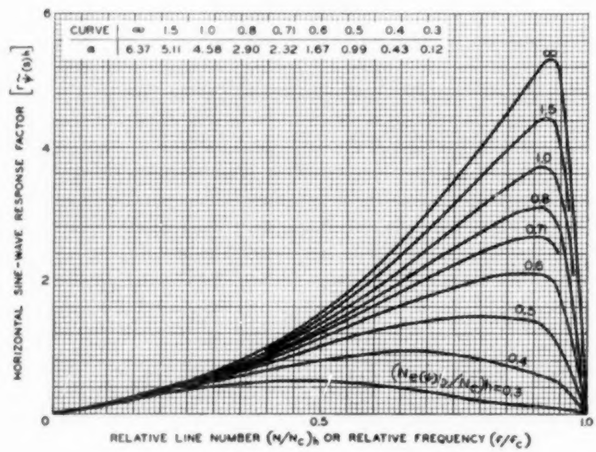


Fig. 91b. Normalized response characteristic for "peaked" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 4× aperture correction (Fig. 81).

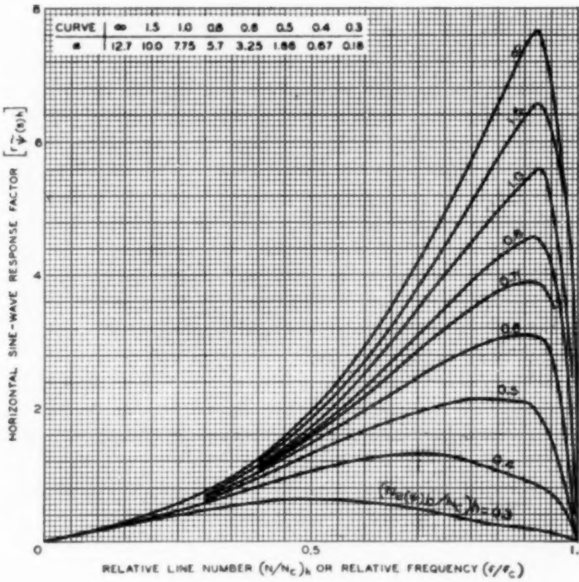


Fig. 91c. Normalized response characteristic for "peaked" channel with sharp-cutoff filter (Fig. 82) in cascade with exponential apertures and 6× aperture correction (Fig. 81).

the impulse function and shown in Fig. 89a for zero phase distortion. The normalizing or "filtering" effect of larger two-dimensional apertures (low α) in cascade with the "abnormal" electrical response characteristics is evident. *The peak-to-peak transient* ripple can be estimated from the α-value by the curve shown in Fig. 89b.

The response characteristics Figs. 86 and 87 include a complete video system and are required for calculation of signal-to-deviation ratios originating in electrical sources ahead of the video amplifier or in photographic grain patterns ahead of the television system. Fluctuations ($\tilde{i}_0$) (see Fig. 65) in the photo-emission current of the camera tubes are usually of negligible magnitude compared to fluctuations ($\tilde{i}_1$) originating in the camera tube beam-current or in the current of the first amplifier stage. (Fluctuations ($\tilde{e}_t$) introduced later in the process of signal transmission (radio links, etc.) vary in magnitude according to distance and will be assumed negligible in this analysis.) The location of the dominating source $\tilde{i}_1$ in the system is shown in more detail in Fig. 90a. The diagram Fig. 90b indicates the response characteristic $r_{\bar{z}1}$ of the capacitive input circuits in which the response decreases with frequency, and following the response characteristic $r_{\bar{z}2}$ (high-peaking circuit) by which the signal response is again corrected to a constant-amplitude response $r_{\bar{z}1}r_{\bar{z}2} = r_{\bar{z}12} = 1$. The equivalent diagram Fig. 90b illustrates that fluctuations $\tilde{e}_1$ originating in a camera tube have a constant-amplitude frequency spectrum and are termed *flat channel noise*. Fluctuations $\tilde{e}_a$ from the first video amplifier are modified in the input-correction circuit to have a sine-

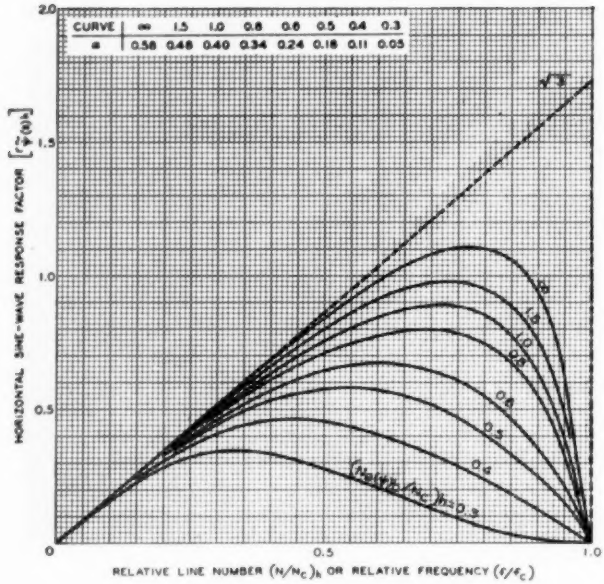


Fig. 92a. Normalized response characteristic for "peaked" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 1× aperture correction (Fig. 81).

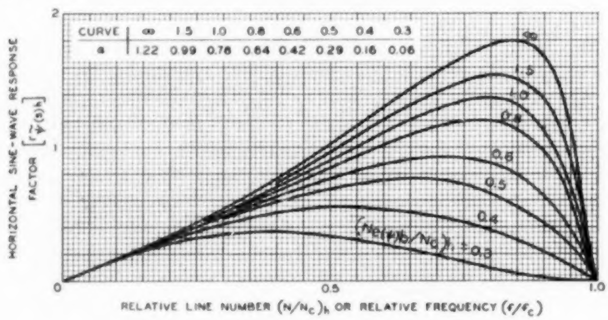


Fig. 92b. Normalized response characteristic for "peaked" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 2× aperture correction (Fig. 81).

wave spectrum with amplitudes proportional to frequency. *This type of fluctuation is termed peaked-channel noise.* The response factor of the theoretical triangular characteristic with sharp cutoff has been normalized to the value $r_{\tilde{\psi}1} = \sqrt{3}$ at $N = N_{c(h)}$ to obtain $N_{c1} = N_{c(h)}$ for the theoretical condition (see section D2.) In cascade with aperture correction circuits ($r_{\tilde{\psi}c}$), the cutoff filter ($r_{\tilde{\psi}f}$), and the apertures ($r_{\tilde{\psi}(h)}$) following the electrical system, the frequency spectrum

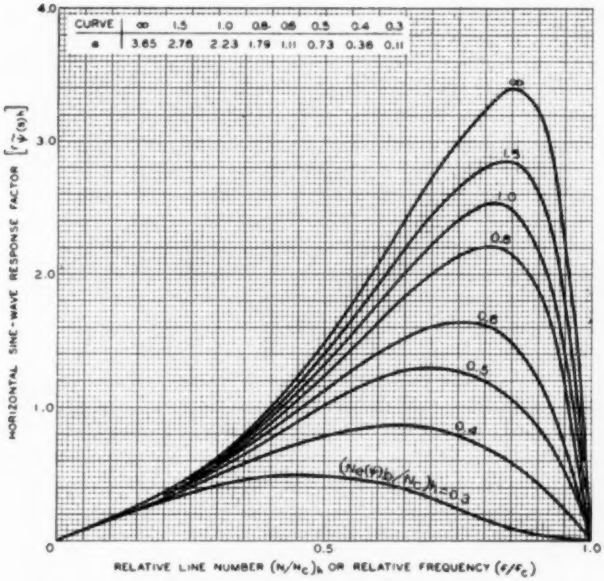


Fig. 92c. Normalized response characteristic for "peaked" channel with gradual-cutoff filter (Fig. 82) in cascade with exponential apertures and 4× aperture correction (Fig. 81).

for peaked channel noise is modified to the forms shown by the normalized response characteristics Figs. 91 and 92.

In the Fourier synthesis of the corresponding aperture transmittance (or impulse shape), the cosine terms are changed to negative sine terms because of a 90° phase shift in the reactive circuit (except for the lowest-frequency terms which can be neglected because of their small amplitude). The impulse waveform or horizontal-aperture transmittance of these characteristics is, therefore, a differentiated pulse as shown in Fig. 93 (obtained by differentiating the corresponding flat-channel pulse shapes (Fig. 88)).

4. Aperture Response of Camera Tubes and Kinescopes

The sine-wave response of *television camera tubes* is measured with the help of vertical and horizontal cross-section selector circuits[3] using sine-wave test patterns or a conversion from square-wave response characteristics. The sine-wave response is determined primarily by the aperture characteristic of an electron beam but is modified by a number of secondary aperture effects, such as image-plate granularity, out-of-focus conditions (particularly in iconoscope and image-iconoscope types which have inclined targets), or the aperture of electron-image sections.

The sine-wave response of camera tubes, decreases, therefore, more rapidly than that of a kinescope and the effective aperture is a composite of several exponential $(\epsilon^{-(r/r_0)^2})$ spot sizes. The sine-wave response of a typical camera tube is shown in Fig. 94. Although measured recently on image orthicons having 3-in. faceplates this characteristic may be regarded as typical of good commercial camera tubes in use at this time, includ-

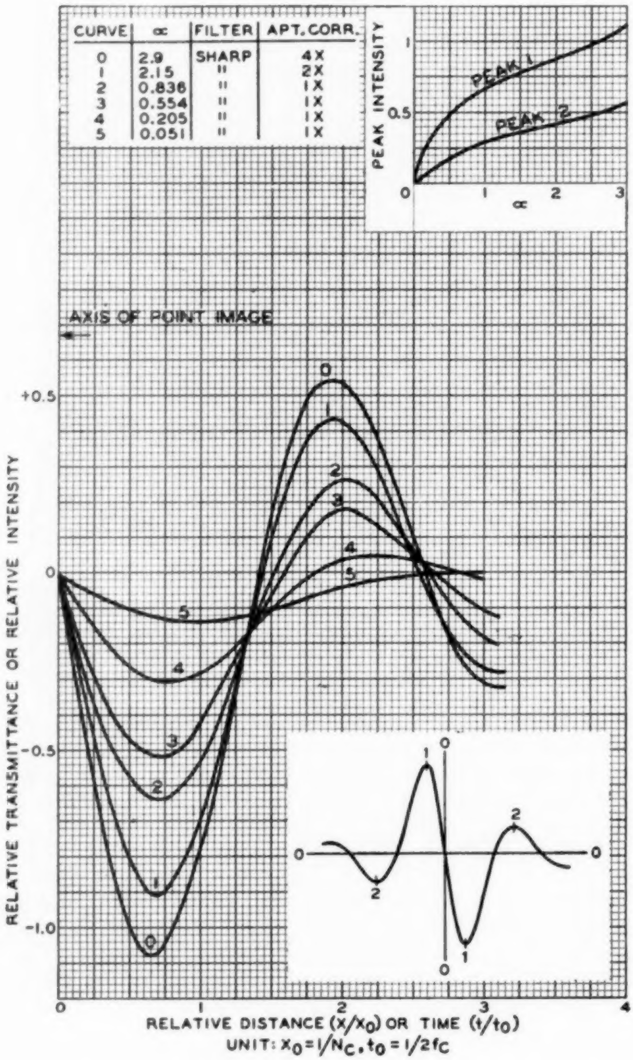


Fig. 93. Impulse forms or aperture transmittance obtained with response characteristics Figs. 91 and 92.

Table XVI. Equivalent Passband $\bar{N}_e$ and Approximate Limiting Resolution N_c of Television Components.

	$\bar{N}_e$	$N_c{}^*$	r_ψ
Square spot $\tau = 1$	$0.49\ N_c{}^*$		Part II, Fig. 41
Round spot $\tau = 1$	$0.45\ N_c{}^*$		" " " 42
Round spot $\tau = \cos^2 r$	$0.38\ N_c{}^*$		" " " 43
Exponential spot $\tau = \epsilon^{-(r/r_0)}$	$0.23\ N_c{}^*$		" " " 46a
Exponential spot $\tau = \epsilon^{-(r/r_0)^2}$	$0.32\ N_c{}^*$		" " " 44
	$0.20\ N_c{}^*$		(av. field luminosity $B \simeq$
Eye at viewing ratio: $d/V = 2$	376	1880	4 to 10 ft-L.)
4	188	940	Fig. 81
8	94	470	
Camera tubes	$\bar{N}_e$	$N_c{}^*$	r_ψ
Image iconoscope	200	800 (approx.)	
Image orthicon (type 5826)	200	800 "	Fig. 94
Image orthicon $4\frac{1}{2}$-in. faceplate	250	1300 "	" 95
Vidicon (type 6198)	158	650 "	" 96
Kinescopes	265	920 "	" 97
	420	1500 "	
	500	1800 "	
	800	3000 "	

$N_c{}^*$ at response $r_\psi \simeq 0.02$.

ing iconoscopes and European orthicon and image-iconoscope types.† According to the author's experience and measurements, there is no evidence supporting statements often found in the literature that high-velocity tubes, such as the iconoscope types, have higher resolution, i.e., a better response characteristic than low-velocity tubes. Theoretical advantages in one type are balanced by disadvantages imposed by tube geometry or auxiliary components in other types. The relative performance of different tubes is often thoughtlessly compared, disregarding large differences in the size of the storage surface and its capacitance. The response characteristics of an experimental high-definition image orthicon having a larger storage surface is shown in Fig. 95, and that of a small vidicon in Fig. 96 (both are low-velocity types).

The equivalent passband $\bar{N}_e$ of the characteristic in Fig. 94 is 200; this value may be regarded as representative of good commercial camera tube performance at the present time. Appropriate values for resolution (N_c) and equivalent passband $\bar{N}_e$ of camera tubes are listed in Table XVI.

The *sine-wave response characteristic of a kinescope* is shown in Fig. 97. The measured electrooptical response departs more or less from that of theoretical electron beams because of aberrations and the additional aperture effect of the particle structure of the screen phosphor. Uniformity of the response in the frame area and resolution depend on the design of the electron gun, electron lens, and the operating conditions. The resolution of kinescope types may vary from a few hundred to several thousand lines. The

† A recent publication[1] claims a resolution limit of 900 to 1000 lines for the center of a modern image iconoscope and about 700 lines at the edges. Low-velocity types have very little astigmatism and a substantially uniform spot diameter for correctly adjusted operating conditions.

response characteristic retains a shape similar to that in Fig. 97. Approximate values of the equivalent passband (N_e) and limiting resolution (N_c) for a variety of kinescopes are listed in Table XVI.

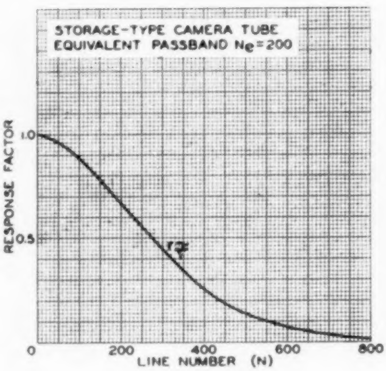
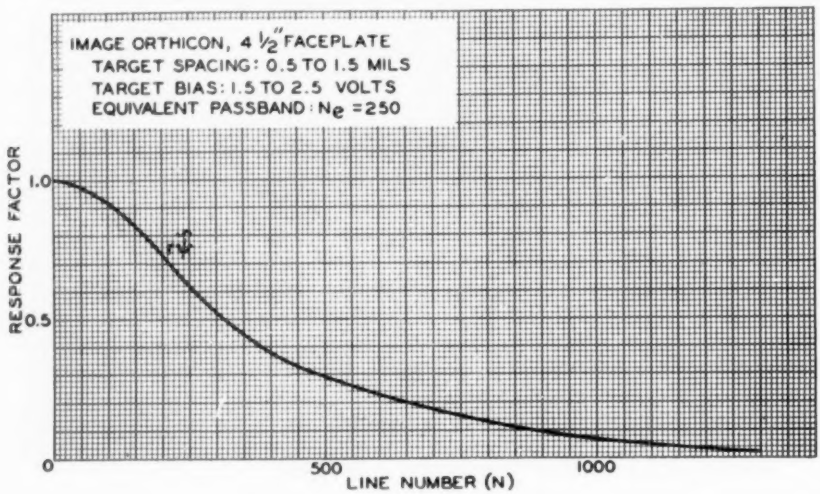


Fig. 94. Sine-wave response (r_ψ) of commercial camera tubes.

Fig. 95. Sine-wave response (r_ψ) of experimental high-definition camera tubes.



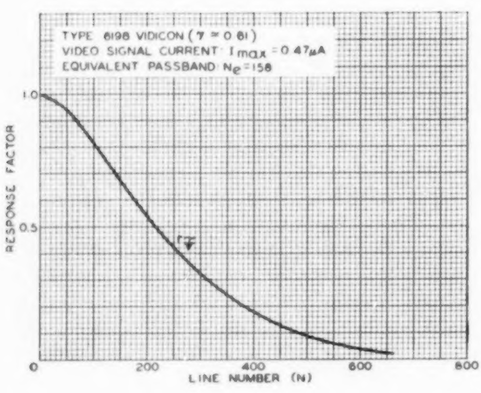


Fig. 96. Sine-wave response (r_ψ) of small camera tube (vidicon) with photoconductive target.

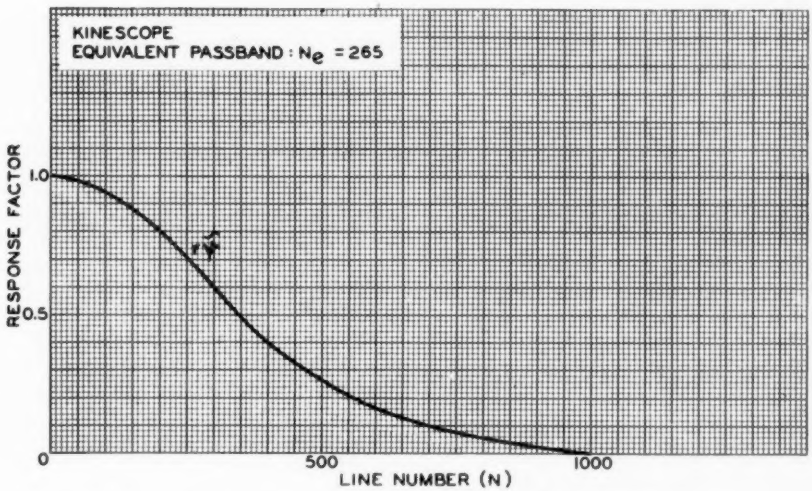


Fig. 97. Sine-wave response (r_{ψ}) of a kinescope.

D. EQUIVALENT PASSBANDS AND SIGNAL-TO-DEVIATION RATIOS

1. General Formulation

The passband of an electrooptical system, such as a television system, has a definite value defined by the electrical cutoff frequency f_c, or more adequately by the passband $\bar{N}_{e(f)} = (N_{c(h)}n_r)^{\frac{1}{2}}$ of the theoretical measuring aperture. Because of the relation $f/f_c = N_{(h)}/N_{c(h)}$, frequencies and line numbers in the horizontal coordinate have been expressed in relative units $(N/N_c)_h$ permitting representation of the system response by generalized characteristics. *The equivalent horizontal passband $N_{e(s)h}$ of an electrooptical system* can hence be stated in the general form

$$N_{e(s)h} = \alpha N_{c(h)} \qquad (66)$$

where

$\alpha = \int_0^1 (r_{\xi} r_{\psi})^2_{(N/N_c)h}\, d(N/N_c)_h$ = relative equivalent passband

$r_{\xi(f/f_c)}$ = response characteristic of electrical system following source of deviations

$r_{\psi(N/N_c)h}$ = response characteristic of aperture system following source of deviations.

The system response in the vertical coordinate is determined completely by the raster constant n_r and the two-dimensional apertures of the system, and has likewise been expressed in relative units N_v/n_r. *The equivalent vertical passband* $N_{e(s)v}$ of the system, can hence be stated in the general form.

$$N_{e(s)v} = \beta n_r \qquad (67)$$

The relative equivalent passband $\beta = N_{e(s)v}/n_r$ is given by Eqs. (59), (60), or Fig. 76. For deviations of electrical origin, the analyzing aperture δ_a is the measuring aperture δ_f of the theoretical television system. (See section C2.) The equivalent vertical passband of $\delta_a = \delta_f$ is hence $N_{e(a)} = n_r$ and the vertical passband of the system is given exactly by Eq. (60), i.e., $N_{e(s)v} = N_{e(b)}$ and $\beta = N_{e(b)}/n_r$.

The factors α and β are defined by Eqs. (56) and (67) as ratios of the equivalent horizontal or vertical passband of the system to the corresponding theoretical passband of the television channel and are, therefore, termed *bandwidth factors*.

The equivalent symmetric passband $\bar{N}_{e(s)}$ of the system is the geometric mean of its equivalent horizontal and vertical passbands:

$$\bar{N}_{e(s)} = (\alpha\beta)^{\frac{1}{2}}(N_{e(h)}n_r)^{\frac{1}{2}} \quad (68)$$

The corresponding bandwidth factor $(\alpha\beta)^{\frac{1}{2}}$ of the system is the geometric mean of the horizontal and vertical bandwidth factors.

By combining Eq. (68) with Eq. (53), the signal-to-deviation ratio $[R]_s$ at any point in an electrooptical system can be stated in the convenient form:

$$[R]_s = [R]_m(\bar{N}_{e(m)}/\bar{N}_{e(f)})/(\alpha\beta)^{\frac{1}{2}}\dot{\gamma}_s \quad (69)$$

The meaning of the symbols is summarized for easy reference:

$[R]_m$ = Signal-to-deviation or signal-to-noise ratio at origin of deviations

$\bar{N}_{e(m)}$ = Equivalent passband of aperture with which $[R]_m$ is computed or measured

$\bar{N}_{e(f)}$ = $(N_{e(h)}n_r)^{\frac{1}{2}}$ = theoretical aperture of television channel

α = Horizontal bandwidth factor (Eq. (66))

β = Vertical bandwidth factor (Eq. (67))

$\dot{\gamma}_s$ = product of all point gammas between origin of deviation and point of observation.

Deviations may originate at a number of points in the electrooptical system indicated in Fig. 65. The deviations from the various sources are computed separately (compare Part II) and combined by forming their rms sum. *Deviations ($\bar{\psi}$) originating in the grain structure of a preceding motion-picture process* are transferred through the entire television system and observed in the final image. *Fluctuations originating in the electrical system* are displayed likewise as two-dimensional deviations in a picture frame, but they are also observed and measured as *signal-to-noise ratios* at various points of the electrical system. In all cases the signal-to-deviation ratio $[R]_s$ or signal-to-noise ratio $[R]$ may be computed with Eq. (69) by determining the proper reference values, bandwidth factors, and point gammas of the system elements involved in the transfer of signals and deviations.

2. The Reference Values $[R]_m$ and $\bar{N}_{e(m)}$

The signal-to-deviation ratio at the source is either computed or determined by measurements with an aperture of known equivalent passband $\bar{N}_{e(m)}$. *Optical deviations $\bar{\psi}$* originate in a photographic system preceding the television process and appear in the projected film image (A_0 in Fig. 65) which can be regarded as the source of deviations. In a motion-picture transmission by a television system, the normal motion-picture projection lens δ_3 is replaced by the lens δ_0 of the television film camera (Fig. 65). When the lenses are of equal quality ($\delta_0 = \delta_3$), the measuring aperture is simply $\bar{N}_{e(m)} = \bar{N}_{e(p)}$, and the reference signal-to-deviation ratio is $[R]_m = [R]_p$, where $\bar{N}_{e(p)}$ and $[R]_p$ are the equivalent passband and signal-to-deviation ratio of the normal motion-picture process as computed in Part II. When the lenses are not identical, $\bar{N}_{e(m)}$ can be computed with $1/\bar{N}_{e(m)}^2 = (1/\bar{N}_{e(p)}^2) - (1/\bar{N}_{e(3)}^2) + (1/\bar{N}_{e(0)}^2)$ and

$$[R]_m = [R]_p(\bar{N}_{e(m)}/\bar{N}_{e(p)})\dot{\gamma}_2/\dot{\gamma}_0 \quad (70)$$

Electrical fluctuations $\bar{i}_0$ in photoelectric currents are normally computed from the number of electrons emitted in a time unit. The signal-to-noise ratio $[R]_0 = [R]_m$ can be obtained by the equivalent two-dimensional formulation given by Eq. (52) where $\bar{n}_0$ is the number of electrons, i.e., the total charge $Q_f/(H/V)$ in the unit area divided by the charge (q_e) of one electron:

$$[R]_m = [R]_0 = \left(\frac{Q_f}{q_e(H/V)}\right)^{\frac{1}{2}}/N_{e(m)} \quad (71)$$

with the frame charge $Q_f = I_0T_fb$ amp sec the electron charge $q_e = 1.6 \times 10^{-19}$ amp sec and the measuring aperture $\bar{N}_{e(m)} = \bar{N}_{e(f)}$ of the theoretical television channel:

$$[R]_0 = \left(\frac{I_0 T_f b\ 10^{19}}{1.6(H/V)}\right)^{\frac{1}{2}} / \bar{N}_{e(f)} \qquad (72)$$

where

I_0 = photo current (amp)
T_f = frame time ($\frac{1}{30}$ sec)
b = $(1 - b_h)(1 - b_v)$ = blanking factor ($b = 0.785$)
H/V = aspect ratio ($H/V = 4/3$)
$\bar{N}_{e(f)}$ = $(N_{e(h)} n_r)^{\frac{1}{2}}$ (see Eq. (64)).

Fluctuations $\bar{i}_1$ in the beam current of television camera tubes can be computed similarly from the values of beam current and storage capacitance of the tube.[3] A reference signal-to-noise ratio $[R]$ is usually given by the manufacturer for a specified frequency channel Δf_s. The reference values for a frequency channel Δf are therefore:

$$[R]_m = [R]_1 = [R](\Delta f_s/\Delta f)^{\frac{1}{2}} \qquad (73)$$

and

$$\bar{N}_{e(m)} = \bar{N}_{e(f)}$$

Camera tubes not having an electron multiplier, such as iconoscopes, image iconoscopes, orthicons (C.P.S. Emitron) and vidicons, require the use of high-gain camera amplifiers. *The current fluctuations $\bar{i}_2$ in the first amplifier tube* become the dominant noise source. All high-gain camera amplifiers have a capacitive input circuit (Fig. 90a) which causes the signal-input voltage on the first amplifier tube to decrease with frequency as indicated in the voltage diagram Fig. 90b. The decreasing sine-wave response $r_{\bar{z}1}$ is, therefore, compensated by a corrective network ($r_{\bar{z}2}$) to a constant signal response $r_{\bar{z}1}r_{\bar{z}2} = 1$. The noise voltage $\bar{e}_a$ generated by the first amplifier current $\bar{i}_2$ is inserted between the input and correction circuits, and its normal "flat" spectrum is modified by the response $r_{\bar{z}2}$ to a spectrum with rising amplitude response termed a "peaked" channel. The amplifier circuit can, therefore, be represented as a flat (compensated) signal channel ($r_{\bar{z}12} = 1$) into which a noise voltage $\bar{e}_a$ is introduced over a peaked channel as indicated by the equivalent voltage diagram Fig. 90c. The rms-value $[\bar{E}]_a$ of the flat-channel noise voltage $\bar{e}_a$ can be computed in first approximation from the "equivalent noise resistance" R_{eq} of the amplifier tube[5] and has the value

$$[\bar{E}]_a = 1.3 \times 10^{-10}(R_{eq}\Delta f)^{\frac{1}{2}} \qquad (74)$$

The corrective network $r_{\bar{z}2}$ changes this value by the factor

$$a_2 = [\bar{E}]_2/[\bar{E}]_a = \left[\int_0^1 (g/g_0)^2_{(f/f_c)} d(f/f_c)\right]^{\frac{1}{2}} \qquad (75)$$

which is the *rms value* of the gain ratio (g/g_0) in the network. In terms of circuit constants the gain ratio is equal to the impedance ratio $\omega L/r$, which in turn must equal the time constant ωCR of the input circuit to obtain a complete compensation $r_{\bar{z}1}r_{\bar{z}2} = 1$. Integration furnishes the value

$$a_2 = (\omega_c CR/\sqrt{3}) = 2\pi\Delta f CR/\sqrt{3} \qquad (76)$$

where

C = effective capacitance of input circuit in farads
R = shunt resistance of input circuit in ohms.

For a general formulation it is expedient to replace the actual noise source $\bar{e}_a$ and the correcting circuit by a noise source $\bar{e}_2$ generating the rms voltage $[\bar{E}]_2$ in a flat channel Δf and to change the spectrum to a "peaked" frequency spectrum by a correction network having a normalized response characteristic and the response factor $r_{\bar{z}2} = \sqrt{3}$ at $f = f_c$. *The normalized characteristic* $r_{\bar{z}2}$ (see broken-line curve in Fig. 91a) does not change the rms value $[\bar{E}]_2$, because for $r_{\bar{z}2} = \sqrt{3}$ at f_c, the rms voltage ratio of the normalized correction network has the value

$$[\bar{E}]_2/[\bar{E}]_a = \left[\int_0^1 (r_{\bar{z}2})^2_{(f/f_c)} d(f/f_c)\right]^{\frac{1}{2}} = 1 \qquad (77)$$

The signal-to-noise ratio $[R]_2$ for amplifier noise (equivalent circuit Fig. 90c) is computed as follows:

The signal is the voltage $\bar{I}R$ developed

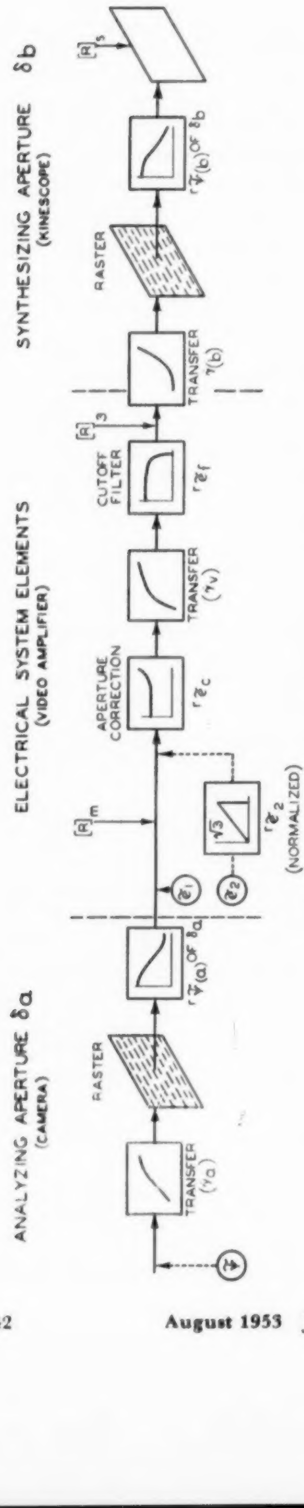


Fig. 98. Noise sources and elements of television process.

by the camera-tube signal current $\bar{I}$ in the input resistance R (Fig. 90a), because the effect of the shunt capacitance C has been compensated by a corrective network. The noise source is considered as a flat-channel noise source having an rms voltage $[\tilde{E}]_2 = a_2[\tilde{E}]_a$. Because of Eq. (77) the noise voltage after the peaking circuit has the same rms value. The measuring aperture for the normalized circuit has the equivalent passband $\bar{N}_{e(m)} = \bar{N}_{e(f)}$ and the signal-to-noise ratio is $[R]_2 = \bar{I}R/a_2[\tilde{E}]_a$. With the values of Eqs. (74) and (76):

$$[R]_2 = 2.13\bar{I} \times 10^9/C(R_{eq})^{\frac{1}{2}}(\Delta f)^{\frac{3}{2}} \qquad (78)$$

The signal-to-noise ratio $[R]_2$ of practical amplifier circuits may have a lower value than the one computed with Eq. (78) which neglects noise contributed by circuit resistances, subsequent amplifier stages, and the effects of feedback. These contributions are usually small for circuits using a pentode input stage (type 6AC7). They are appreciable for a normal triode input stage but may be minimized by the use of special circuits and tubes having low grid-plate capacitance. A typical input stage used in older camera amplifiers uses a type 6AC7 amplifier tube as a pentode with the following constants:

$$R_{eq} = 720 \text{ ohm}, \; C = 30 \times 10^{-12} \text{ farad}, \; R = 10^5 \text{ ohm}$$

The maximum signal current $\bar{I}_{(max)}$ from camera tubes not having an electron multiplier is of the same order: $\bar{I}_{(max)} \simeq 0.1 \times 10^{-6}$ amp. With these values Eq. (78) furnishes the value $[R]_{2\,max} = 30$ in a frequency channel $\Delta f = 4.25 \times 10^6$ cycles/sec.

Modern high-gain camera amplifiers use special high-transconductance triodes with a somewhat higher effective capacitance but a much lower equivalent noise resistance $R_{eq} \simeq 110$ ohm in a "cascode" circuit, resulting in an improved signal-to-noise ratio $[R]_{2\,max} \simeq 70$ for $\Delta f = 4.25 \times 10^6$ cycles/sec. The variation of $[R]_2$ as a function of signal current, fre-

quency channel or other parameters is readily computed with Eq. (78). Reference values for various camera-tube types are listed in Table XVII.

3. Bandwidth Factors

The ratios of the equivalent passbands of an electrooptical system to the theoretical equivalents $N_{e(\delta)}$ and n_r of its electrical system (Eqs. (66), (67), (68)) have been termed bandwidth factors. A system containing two-dimensional apertures has horizontal and vertical bandwidth factors α and β and its equivalent symmetric aperture has a bandwidth factor $(\alpha\beta)^{\frac{1}{2}}$ which is their geometric mean. *The horizontal bandwidth factor* α includes the response r_ψ of two-dimensional apertures as stated by Eq. (66). It is used to compute the signal-to-deviation ratio in the final image frame for deviations originating (1) in a photographic process ahead of the television system or (2) in electrical noise sources. In case 1 the two-dimensional aperture response is $r_\psi = (r_{\psi(a)}r_{\psi(b)})$. In case 2, $r_\psi = r_{\psi(b)}$, because only apertures following the electrical network are in the system ($r_{\psi(b)}$ may include the response of the eye). Integration of the squared normalized response characteristics Figs. 86 and 87 furnishes electrooptical bandwidth factors α for case 1 and for case 2 with electrical flat channel noise sources $\tilde{e}_1$. For convenience in plotting, the corresponding square roots $\alpha^{\frac{1}{2}}$ are shown in Fig. 99. The bandwidth factors for peaked channel noise sources $\tilde{e}_2$ have been computed similarly for the characteristics Figs. 91 and 92, and their square roots are shown in Fig. 100.

For deviations ψ of optical origin, the vertical bandwidth factor β may be obtained from Fig. 76 or computed with Eqs. (59) or (60). For deviations of electrical origin ($\tilde{e}_1$ or $\tilde{e}_2$) the exact value of the vertical bandwidth factor of the system is given by

$$\beta = (N_{e(b)}/n_c) \qquad (81)$$

It has been shown that the electrical circuit response of a television system has no effect on the vertical aperture response of the system. The vertical bandwidth factor β of electrical elements is, therefore, $\beta = 1$. The bandwidth fac-

Table XVII. Maximum Signal-to-Noise Ratios $[R]_{m\,(\max)}$ of Various Camera-Tube Types for Theoretical Channel $\Delta f = 4.25$ Mc.

Tube type	Use	Approx. target capacitance ($\mu\mu f$)	$\hat{I}(\mu a)$	$[R]_{m\,\max}$	Noise** source	Spectrum
Iconoscope	Film Pickup	10000	0.1	70	$\tilde{e}_2$	peaked
Vidicon type 6198	Film "	2200	0.45	315	$\tilde{e}_2$	peaked
Image iconoscope	Live "	6000	0.1	70	$\tilde{e}_2$	peaked
Orthicon* (without multiplier)	Live "	700	0.1	70	$\tilde{e}_2$	peaked
Image orthicon						
Type 5820	Live "	100	10	34	$\tilde{e}_1$	flat
5826	Live "	375	10	66	$\tilde{e}_1$	flat
High-definition ($4\frac{1}{2}$-in. faceplate) image orthicon	Live "	1100	20–40	120	$\tilde{e}_1$	flat

* Similar to C.P.S. Emitron.

** See Fig. 98.

Note: $[R]_{m\,\max}$ for $\tilde{e}_2$ is obtained only with modern cascode input circuits (see text).

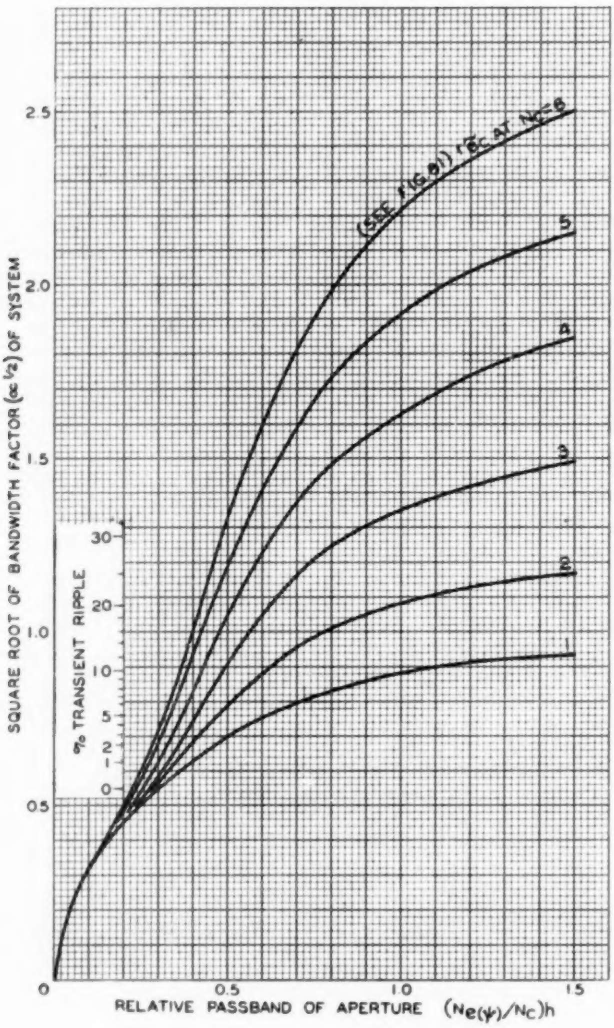


Fig. 99a. Bandwidth factors for "flat" channel noise sources with sharp-cutoff filter (Fig. 82) and aperture correction (Fig. 81) in cascade with exponential aperture.

tor $(\alpha\beta)^{\frac{1}{2}}$ of the equivalent aperture of electrical networks in an electrooptical system (excluding optical elements) has, therefore, a value $m^{\frac{1}{2}} = \alpha^{\frac{1}{2}}$, i.e., it is equal to the square root of its horizontal bandwidth factor m. The new symbol m is introduced to avoid confusion and indicate that this factor is reserved for purely electrical systems. According to Eq. (66), *electrical bandwidth factors* m are defined by

$$m = (\Delta f_e/\Delta f) = \int_0^1 (r_{\bar{c}})^2{}_{(f/f_c)} d(f/f_c) \quad (79)$$

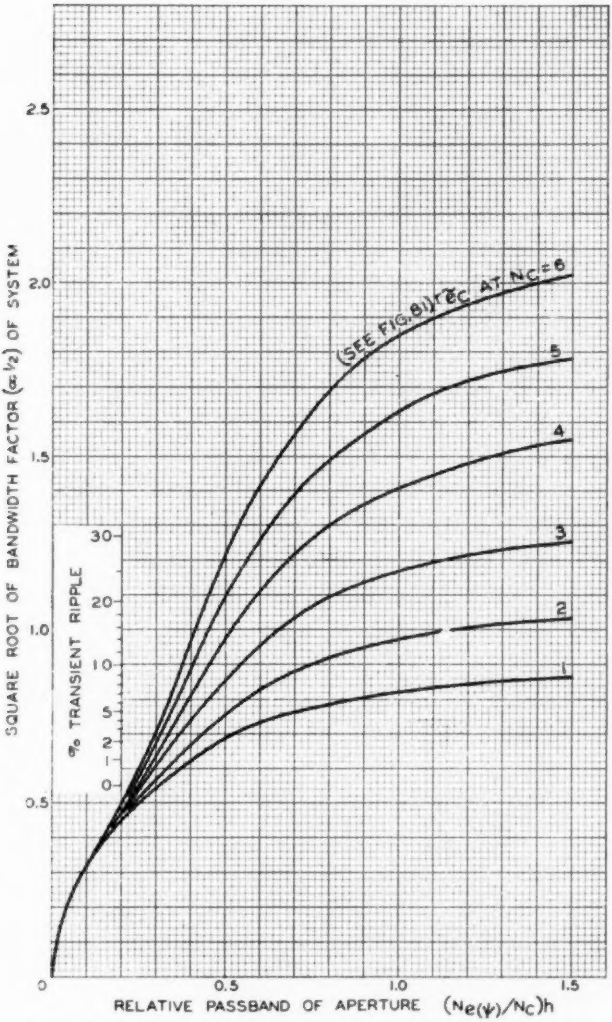


Fig. 99b. Bandwidth factors for "flat" channel noise sources with gradual-cutoff filter (Fig. 82) and aperture-correction circuits (Fig. 81) in cascade with exponential apertures.

where

Δf_e = noise-equivalent passband of the electrical system

Δf = theoretical (rectangular) passband of electrical system

r_7 = sine-wave response factor of electrical system.

4. Signal-to-Noise Ratios in the Electrical System

The signal-to-noise ratio $[R]$ at different points in the electrical system (compare Eq. 69) reduces to

$$[R] = [R]_m / m^{\frac{1}{2}} \dot{\gamma}_e \qquad (80)$$

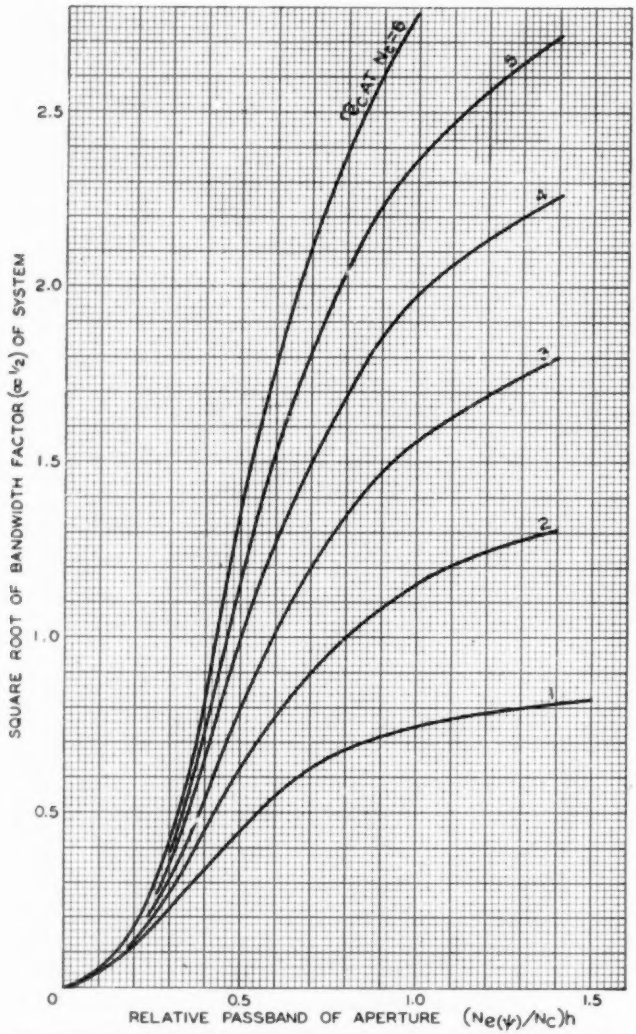


Fig. 100a. Bandwidth factors for "peaked" channel noise sources with sharp-cutoff filter (Fig. 82) and aperture correction (Fig. 81) in cascade with exponential apertures.

where

$[R]_m$ = signal-to-noise ratio computed for the theoretical passband Δf at the point of noise insertion (see preceding section)

m = electrical bandwidth factor computed for the frequency response $r_{\overline{z}}$ between the noise source and the point of observation (Eq. (79))

$\dot{\gamma}_v$ = point gamma of video amplifier between noise source and point of observation.

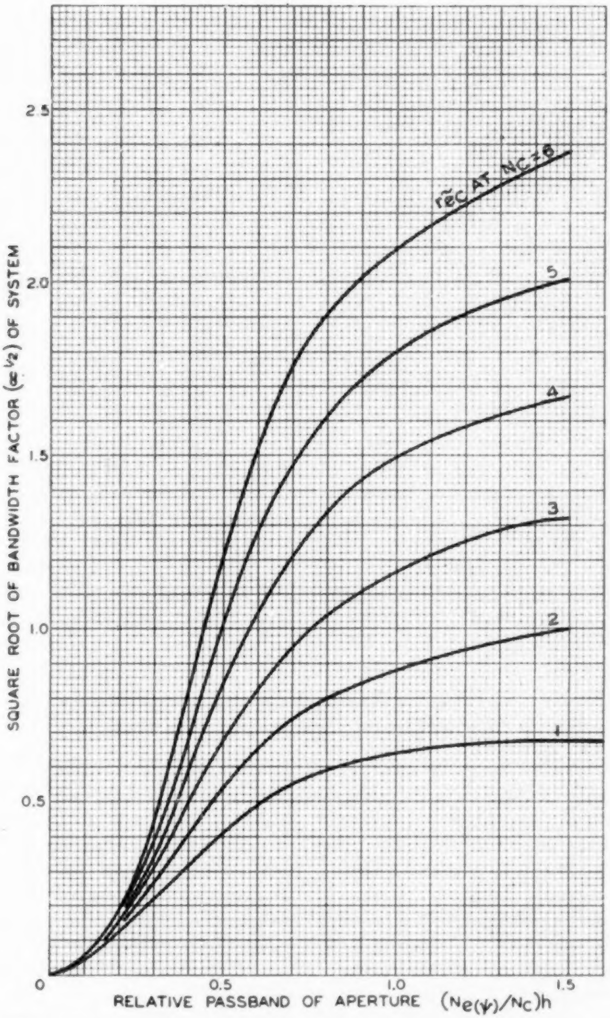


Fig. 100b. Bandwidth factors for "peaked" channel noise sources with gradual-cutoff filter (Fig. 82) and aperture correction (Fig. 81) in cascade with exponential apertures.

Actual measurements of the electrical signal-to-noise ratio are necessarily made at points following a cutoff filter, indicated in Fig. 98 by the index number 3. Figure 98 indicates all important electrical sources, the characteristics of the electrical system and the succeeding aperture system δ_b. The square roots $m^{\frac{1}{2}}$ of the bandwidth factors for circuit elements between the noise sources $\bar{e}_1$ (camera tube noise) or $\bar{e}_2$ (amplifier noise) have been computed for two filter

Table XVIII. Square Roots of Electrical Bandwidth Factors $m^{\frac{1}{2}}$.

Cutoff filter (Fig. 82)	Aperture correction at N_c (Fig. 81)	Noise source $\bar{e}_1$ (flat spectrum) $m_{13}^{\frac{1}{2}}$	Noise source $\bar{e}_2$ (peaked spectrum) $m_{23}^{\frac{1}{2}}$
Sharp	1 ×	0.98	0.914
"	2 ×	1.26	1.47
"	3 ×	1.63	2.0
"	4 ×	2.02	2.52
"	5 ×	2.4	3.04
"	6 ×	2.76	3.57
Gradual	1 ×	0.90	0.76
"	2 ×	1.09	1.10
"	3 ×	1.36	1.50
"	4 ×	1.68	1.91
"	5 ×	1.99	2.31
"	6 ×	2.24	2.70

characteristics ($r_{\bar{\gamma}f}$) and four values of aperture correction ($r_{\bar{\gamma}c}$), and are listed in Table XVIII.

The calculation of signal-to-noise ratios $[R]$ in the electrical system and signal-to-deviation ratios $[R]_s$ in the final image by means of Eqs. (80) and (69) respectively, is now a simple operation because the bandwidth factors m, α, and β or their square roots have been tabulated or plotted. The values $[R]_s$ change with signal level and point gamma ($\dot{\gamma}$) as in photographic systems. A comparison requires, therefore, evaluation of the *signal-to-deviation characteristic* $[R]_s$ as a function of screen luminance.

E. THE SIGNAL-TO-DEVIATION CHARACTERISTIC $[R]_s = f(B)$ OF TELEVISION PICTURE FRAMES

Television-signal generators and camera tubes may be divided into two groups. One group, including light-spot scanners (flying-spot scanner) and image-dissector tubes, has no charge-storing elements and operates without auxiliary currents. The photoelectric signals are amplified by built-in electron multipliers and have a sufficiently large magnitude to make the noise contribution by amplifier tubes negligible. The signal-to-noise ratio $[R]_m$ is therefore a function of the *photocurrent* only (Eq. 72) and varies as the half power of the signal current:

$$[R]_m = [R]_0 = [R]_{0\ \max} (I/\hat{I})^{\frac{1}{2}} \quad (82)$$

The second group of camera tubes has charge-storing elements (mosaics or targets), and employs electron beams for signal development. This group includes camera tubes having photo-emissive surfaces such as are used in the iconoscope, image iconoscope, orthicon and image orthicon, or photoconductive layers as used in the vidicon. The image orthicon is the only type in use having a built-in electron multiplier. It can, therefore, develop large signals and has a "flat" noise spectrum like that of multiplier phototubes. The signal-to-noise ratio $[R]_m = [R]_1$, however, varies in direct proportion to the signal current, because the dominant noise source is the *constant-beam current*

$$[R]_m = [R]_1 = [R]_{1\ \max} (I/\hat{I}) \quad (83a)$$

The camera tubes not having electron multipliers (iconoscope and orthicon and vidicon types) have a relatively small signal-current output. Their signal-to-noise ratio $[R]_m = [R]_2$ is controlled by the constant *amplifier noise* (Eq. (78))

which has a "peaked" frequency spectrum and $[R]_2$ varies in proportion to the signal current:

$$[R]_m = [R]_2 = [R]_{2\,max}\,(I/\hat{I}) \quad (83b)$$

The optical signal-to-deviation ratio $[R]_s$ *in one picture frame* is computed with Eq. (69). With the substitutions from Eqs. (82) or (83) for $[R]_m$, and with $\bar{N}_{e(m)} = \bar{N}_{e(f)}$, the optical signal-to-deviation ratio for the first group of signal sources may be written:

$$[R]_s = [R]_{0\,max}\,(I/\hat{I})^{\frac{1}{2}}/(\alpha\beta)^{\frac{1}{2}}\dot{\gamma}_v\dot{\gamma}_b \quad (84)$$

and for the second group of storage tubes:

$$[R]_s = [R]_{1\,max}\,(I/\hat{I})/(\alpha\beta)^{\frac{1}{2}}\dot{\gamma}_v\dot{\gamma}_b \quad (85a)$$

and

$$[R]_s = [R]_{2\,max}\,(I/\hat{I})/(\alpha\beta)^{\frac{1}{2}}\dot{\gamma}_v\dot{\gamma}_b \quad (85b)$$

where

$\dot{\gamma}_v$ = point gamma of video amplifier system

$\dot{\gamma}_b$ = point gamma of succeeding aperture processes including kinescope ($\dot{\gamma}_2$)

$[R]_0$ and $[R]_1$ = signal-to-noise ratios with "flat" noise spectrum

$[R]_2$ = signal-to-noise ratio with "peaked" noise spectrum

1. Effect of Transfer Characteristics and Point Gamma on $[R]_s$

The relation of luminance (B) in a picture frame to the signal current I and scene luminance or camera-tube exposure (E_1) is determined by the transfer characteristics of the system elements. A valid comparison of the signal-to-deviation ratios obtained with different television-camera types requires that the overall transfer characteristic (tone scale) of the system be identical. This requirement is met when the point gammas $\dot{\gamma}_T = \dot{\gamma}_1\dot{\gamma}_v\dot{\gamma}_b$ of the television systems are alike at the same luminance values. It is of interest to examine first the general effect of the camera-tube gamma ($\dot{\gamma}_1$) on the shape of the signal-to-deviation characteristic $[R]_s = f(B)$, which determines the relative visibility of deviations in the luminance range.

The $[R]_s$-characteristic can have different shapes depending on the camera-tube gamma ($\dot{\gamma}_1$), even though the overall gamma of the television system has fixed values $\dot{\gamma}_T$.

(*a*) *The Relative Signal-to-Deviation Ratios* $[R]_s/[R]_{max}$ *of Constant Gamma Systems With Camera Tubes Having Constant Gamma.* It is assumed that the system gamma γ_T as well as the camera-tube gamma $\dot{\gamma}_1$ have constant values. The relative-signal current of the camera tube is then simply $I/\hat{I} = (E_1/\hat{E}_1)^{\gamma_1}$, where $(E_1/\hat{E}_1)$ is the relative exposure. With this relation and the substitutions $\dot{\gamma}_v\dot{\gamma}_b = \gamma_T/\gamma_1$ Eq. (85a) takes the form:

$$[R]_s = [R]_{1\,max}\,(E_1/\hat{E}_1)^{\gamma_1}/(\alpha\beta)^{\frac{1}{2}}$$

In terms of screen luminance $(B/\hat{B}) = (E_1/\hat{E}_1)^{\gamma_T}$, this expression may be written

$$[R]_s = [R]_{1\,max}\,(B/\hat{B})^{\gamma_1/\gamma_T}(\gamma_1/\gamma_T)/(\alpha\beta)^{\frac{1}{2}} \quad (86)$$

Inspection of Eq. (86) shows that the slope of the $[R]_s$-characteristic is controlled by the exponent (γ_1/γ_T) of the relative screen luminance $(B/\hat{B})$. A plot of Eq. (86) furnishes straight-line characteristics in log coordinates with a maximum value $[R]_s/[R]_{1\,max} = (\gamma_1/\gamma_T)/(\alpha\beta)^{\frac{1}{2}}$ at $(B/\hat{B}) = 1$ and the constant slope (γ_1/γ_T) as shown in Fig. 101 for $(\alpha\beta) = 1$ and an overall constant gamma $\gamma_T = 1.2$. It is seen from Fig. 101 that only a minor improvement of $[R]_s$ is obtained in the shadow tones $B/\hat{B} = 0.01$ to 0.04 by decreasing γ_1 below the value $\gamma_1 = 0.6$ at the expense of a larger reduction of $[R]_s$ in the highlight values $B/\hat{B} = 0.2$ to 1. The preferred camera-tube gamma for a constant-system gamma $\gamma_T = 1.2$ is therefore γ_1 optimum $\simeq 0.6$.

(*b*) *The relative signal-to-deviation ratios* $[R]_s/[R]_{max}$ *of systems with variable gamma.* It is impractical and actually undesirable to provide a constant overall gamma for the television system because of the finite limits imposed on the tone range by all practical imaging devices. According to photographic experience

Table XIX. Relative Signal-to-Deviation Ratios $[R]_s/[R]_{1\ max}$ for Image Orthicon (Also Iconoscope Film Pickup)* With Linear Amplifier ($\gamma_v = 1$), Kinescope Bias $E_0/\hat{E} = 0.13$ (Fig. 21, Part I) and $\alpha\beta = 1$.

$E_1/\hat{E}_1$	$I/\hat{I}$	$B/\hat{B}$	$\dot{\gamma}_v\dot{\gamma}_2$	$[R]_s/[R]_{1\ max}$	$\dot{\gamma}_1$	$\dot{\gamma}_T$
0.01	0.026	0.015	0.17	0.153	1.15	0.20
0.02	0.057	0.0185	0.40	0.142	1.15	0.46
0.04	0.125	0.031	0.95	0.132	1.10	1.045
0.07	0.22	0.06	1.45	0.152	0.85	1.23
0.10	0.295	0.095	1.70	0.174	0.75	1.275
0.20	0.47	0.22	1.90	0.247	0.58	1.10
0.40	0.69	0.46	2.00	0.345	0.49	0.98
0.70	0.88	0.77	2.05	0.429	0.39	0.80
1.00	1.00	1.00	2.10	0.476	0.31	0.65
(1)	(1)(2)	(2)	(3)	(4)	(5)	

Notes: (1) From Fig. 6, Part I. (2) From Fig. 21, Part I, ($I/\hat{I} = E/\hat{E}$). (3) $\dot{\gamma}_v = 1$. (4) Eq. (83a). (5) From Fig. 7, Part I.

* Transfer characteristic for $E_1 \simeq 15$, Fig. 11, Part I.

Table XX. Relative Signal-to-Deviation Ratios $[R]_s/[R]_{2\ max}$ for Image Iconoscope, and Orthicon ($\gamma_1 = 1$).

	Image iconoscope*				Orthicon, linear vidicon, $\gamma_1 = 1$		
$E_1/\hat{E}_1$	$I/\hat{I}$	$\dot{\gamma}_1$	$\dot{\gamma}_v\dot{\gamma}_2$	$[R]_s/[R]_{2\ max}$	$I/\hat{I}$	$\dot{\gamma}_v\dot{\gamma}_2$	$[R]_s/[R]_{2\ max}$
0.01	0.0035	3.3	0.06	0.058	0.01	0.2	0.051
0.02	0.019	1.9	0.242	0.079	0.02	0.46	0.045
0.04	0.06	1.45	0.72	0.084	0.04	1.045	0.038
0.07	0.12	1.15	1.07	0.112	0.07	1.23	0.057
0.10	0.18	1.0	1.275	0.141	0.10	1.275	0.079
0.20	0.33	0.85	1.3	0.254	0.20	1.10	0.182
0.40	0.58	0.70	1.40	0.414	0.40	0.98	0.41
0.70	0.82	0.56	1.43	0.573	0.70	0.80	0.875
1.00	1.00	0.50	1.30	0.77	1.00	0.65	1.54

*Transfer characteristic similar to iconoscope for $E_1 \simeq 4$, Fig. II, Part I.

Table XXI. Relative Signal-to-Deviation Ratios $[R]_s/[R]_{max}$ for Vidicon ($\gamma_1 = 0.6$) and Light-Spot Scanner ($\gamma_1 = 1$).

	Vidicon, $\gamma_1 = 0.6$			Light-spot scanner, $\gamma_1 = 1$			
$E_1/\hat{E}_1$	$I/\hat{I}$	$\dot{\gamma}_v\dot{\gamma}_2$	$[R]_s/[R]_{2\ max}$	$I/\hat{I}$	$(I/\hat{I})^{\frac{1}{2}}$	$\dot{\gamma}_v\dot{\gamma}_2$	$[R]_s/[R]_{0\ max}$
0.01	0.064	0.33	0.194	0.01	0.10	0.20	0.51
0.02	0.097	0.77	0.126	0.02	0.141	0.46	0.308
0.04	0.148	1.74	0.085	0.04	0.20	1.045	0.191
0.07	0.205	2.05	0.10	0.07	0.264	1.23	0.215
0.10	0.255	2.12	0.12	0.10	0.316	1.275	0.248
0.20	0.385	1.84	0.21	0.20	0.447	1.10	0.406
0.40	0.57	1.64	0.348	0.40	0.631	0.98	0.645
0.70	0.80	1.34	0.596	0.70	0.835	0.80	1.045
1.00	1.00	1.08	0.93	1.00	1.00	0.65	1.54

the most pleasing transfer characteristics are s-shaped as shown by Fig. 102 with a center-range gamma in the order of 1.2. The transfer characteristics obtained with linear amplifiers ($\gamma_v = 1$) from *iconoscopes used for motion-picture film pickup* or from *image orthicons* (studio pickups) are similar to that of a motion-picture process and will therefore be used as a representative standard.† For comparison the amplifier gamma ($\dot{\gamma}_v$) for all other camera-tube types will be adjusted to result in a system gamma (γ_T) and a transfer characteristic equal to curve 1 in Fig. 102.

Because the video amplifier is linear ($\gamma_v = 1$), the relative-signal voltage $E/\hat{E}$ at the kinescope grid is directly equal to the relative-signal current $I/\hat{I}$ from the camera tube. Corresponding values of screen luminance $B/\hat{B}$ and $\dot{\gamma}_2$ for the signals $E/\hat{E} = I/\hat{I}$ obtained from a representative kinescope characteristic (Fig. 21, Part I) are listed in columns 3 and 4 of Table XIX. The relative signal-to-deviation ratio $[R]_s/[R]_{1\ max}$ computed with Eq. (85a) for $\alpha\beta = 1$, $\gamma_v = 1$ and $\dot{\gamma}_b = \dot{\gamma}_2$ is tabulated in column 5, and shown by curve 1 in Fig. 103. Columns 6 and 7 of Table XIX list the point-gamma values of the image orthicon (Fig. 7, Part I) and the point gamma ($\dot{\gamma}_T$) of the overall system characteristic curve 1 in Fig. 102.

The signal-to-deviation characteristic for an *image-iconoscope* camera chain giving an identical overall transfer characteristic is readily computed by tabulating its signal-current ratio $I/\hat{I}$ and $\dot{\gamma}_1$ for the same relative exposure values $E_1/\hat{E}_1$ as listed in Table XX. The product $\dot{\gamma}_v\dot{\gamma}_2 = \gamma_T/\gamma_1$ is then computed for the desired values $\dot{\gamma}_T$ of Table XIX. The corre-

† A different reference characteristic would not change relative performance values between television-camera tubes.

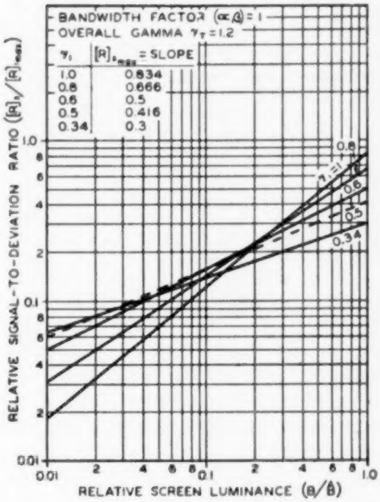


Fig. 101. Relative signal-to-deviation ratio of television systems having the same constant overall gamma and constant "flat" channel noise-level, but camera tubes with different constant gamma values.

sponding signal-to-deviation ratios are shown as curve 3 in Fig. 103. Table XX also lists the values obtained similarly for an *orthicon* or a *linear vidicon* camera ($\gamma_1 = 1$). The relative signal-to-deviation ratios for a *vidicon with low constant gamma* ($\gamma_1 = 0.6$) and *a light-spot scanner* ($\gamma_1 = 1$) are given in Table XXI. The values for the light-spot scanner phototube signals require calculation of $(I/\hat{I})^{\frac{1}{2}}$ because of Eq. (84). The preferred characteristic for camera tubes (curves 1 to 5 in Fig. 103) is that of the image orthicon and iconoscope (curves 1 and 2) which is a close approach to the characteristic obtained from a theoretical constant-gamma system with a camera-tube gamma $\gamma_1 = 0.6$. The previous conclusion that a $\gamma_1 = 0.6$ is optimum does, therefore, not apply to a system with variable gamma as seen by comparison of curve 5 of Fig. 103 with curve 0.6 of Fig. 101.

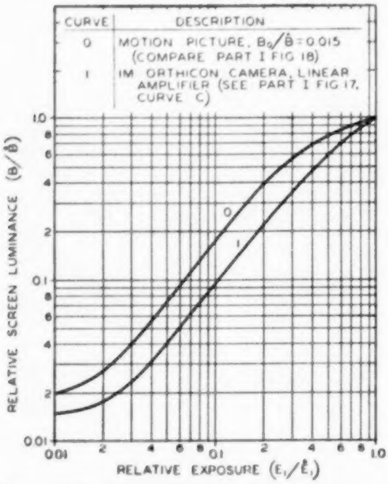


Fig. 102. Transfer characteristics of motion-picture and television processes.

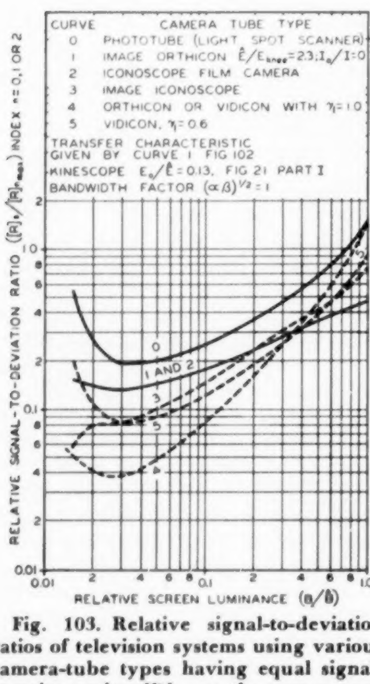


Fig. 103. Relative signal-to-deviation ratios of television systems using various camera-tube types having equal signal-to-noise ratios $[R]_m$ at the source and gamma correction to obtain the transfer characteristic 1, Fig. 102.

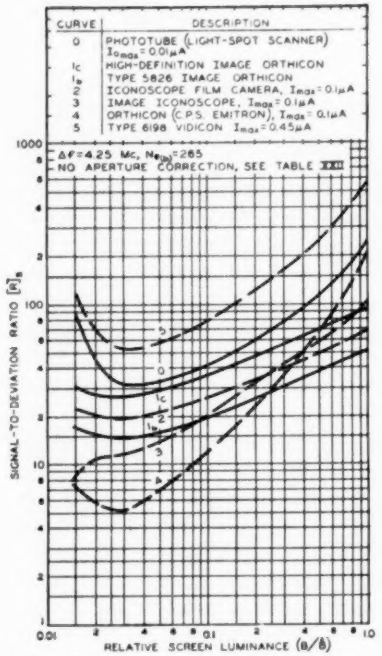


Fig. 104a. Signal-to-deviation ratios at the screen of standard 525-line USA television systems using an average kinescope ($N_{e(\delta)}$ = 265), no aperture correction, but gamma correction to obtain the transfer characteristic 1, Fig. 102.

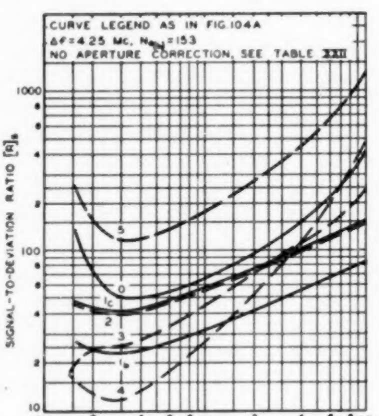


Fig. 104b. Signal-to-deviation ratios in the retinal image for the conditions of Fig. 104a modified by a viewing distance d = 4V, which changes $N_{e(\delta)}$ to 153.

2. Signal-to-Deviation Characteristics of Image Frames on the Kinescope Screen and at the Retina of the Eye

The signal-to-deviation characteristics in Fig. 103 are relative characteristics computed for identical transfer characteristics (curve 1, Fig. 102), identical signal-to-noise ratios at the source, and bandwidth factors $(\alpha\beta)^{\frac{1}{2}} = 1$. A numerical comparison of image granularity requires adjustment of the $[R]_s$-scale according to actually obtained signal-to-noise ratios $[R]_m$ and bandwidth factors $(\alpha\beta)^{\frac{1}{2}}$ for representative electrical systems and succeeding optical apertures $(N_{e(b)})$. The characteristics $[R]_s = f(B/\hat{B})$ are obtained according to Eqs. (84) and (85) by multiplication of the relative characteristics in Fig. 103 with appropriate scale factors $[R]_{m\ max}/(\alpha\beta)^{\frac{1}{2}}$. Electrical aperture correction and variation of the optical aperture passband $N_{e(b)}$ have a considerable effect on the numerical values $[R]_s$, which differ substantially for flat- and peaked-channel noise sources. The relative magnitude and appearance of deviations in the retinal image vary with viewing distance and can be computed by including the aperture process of the eye in the value $N_{e(b)}$ as shown in the following examples.

Without aperture correction ($r_{\bar{z}c} = 1$ *at* N_c) the factors $m^{\frac{1}{2}}$ and $\alpha^{\frac{1}{2}}$ of the system are determined by the type of noise source (flat or peaked), the cutoff filter, and the equivalent passband $N_{e(b)}$ of the optical apertures following the point of noise insertion, while $\beta^{\frac{1}{2}}$ is determined by n_r and $N_{e(b)}$ only. The values computed for a standard (U.S.A.) monochrome television channel and a typical kinescope are given in Table XXII and Figs. 104a and 104b. When the passband $N_{e(b)}$ of the optical-system apertures is changed, the $[R]_s$-characteristics for all camera chains with flat-channel noise sources are shifted as a group with respect to the group of $[R]_s$-characteristics for camera chains with peaked-channel noise sources because the difference in the horizontal frequency spectra causes $\alpha^{\frac{1}{2}}$ to change by different factors (see Figs. 99 to 100). *The visual appearance of grain structures* depends on the granularity of the retinal image which can be computed as follows. For direct-viewing conditions the equivalent passband $N_{e(b)}$ is the cascaded value for the kinescope (N_{e2}) and the eye $(N_{e(eye)})$, which varies as a function of viewing distance, and may be obtained for an average field luminance of 4 to 10 ft-L from:

$$N_{e(eye)} = 752\,(V/d) \qquad (87)$$

The characteristics in Fig. 104a represent, therefore, a close viewing distance where $N_{e(b)}$ is substantially equal to the equivalent passband of the kinescope: $N_{e(b)} \simeq N_{e2} = 265$. An increase of the viewing ratio to $d/V = 4$ changes $N_{e(eye)}$ to 188 and the cascaded value (Eq. (30b), Part II) of kinescope and eye to $N_{e(b)} = 153$, resulting in the characteristics given in Fig. 104b. Before conclusions can be drawn, it is advisable to consider the effects of aperture correction.

Aperture correction ($r_{\bar{z}c} > 1$ *at* N_c) is used to increase the high-frequency sine-wave signals from the camera tube in order to obtain better definition. The magnitude of the correction depends on the response of the camera tube and varies, therefore, for different tube types. A change of the high-frequency response of the video amplifier, however, alters its relative passband and the bandwidth factors m and α. A proper comparison of $[R]_s$-characteristics from different camera tubes should therefore be based on the additional condition that the horizontal sine-wave response $r_{\psi 1} r_{\bar{z}}$ of camera tube, aperture-correcting circuit, and electrical filter is adjusted to be substantially alike. The correction required for each case can be determined as follows. Assume that it is desired to obtain a response $r_{\psi 1} r_e$ equal to that of the sharp-cutoff filter shown in Fig. 82. This filter has a factor $m^{\frac{1}{2}} = 0.975$. It is only necessary to determine the bandwidth factor $\alpha_1 = (N_{e1}/N_c)_h$ of the camera tube, locate it

Table XXII. Maximum Signal-to-Deviation Ratios $[R]_{s\,\max}$ of 525-line Television System With $\Delta f = 4.25$ Mc, Transfer Characteristic Curve 1, Fig. 103, No Aperture Correction ($r_{\dot{\gamma}_c} = 1$ at N_e).

Curve No.	Type of signal source	$[R]_{m\,\max}$	$m^{\frac{1}{2}}$	$\dot{\gamma}_v$	$[R]_{3\,\max}$	$N_{e(b)} = 265$ (Kinescope) $\beta^{\frac{1}{2}}$	$\alpha^{\frac{1}{2}}$	$\dot{\gamma}_s$	$[R]_{s\,\max}$	$\bar{N}_{e(s)}$	$N_{e(b)} = 153$ (Kinc. + eye for $d/V = 4$) $\beta^{\frac{1}{2}}$	$\alpha^{\frac{1}{2}}$	$[R]_{s\,\max}$	$\bar{N}_{e(s)}$
0	Light-spot scanner, $I_{\max} \simeq 0.01\mu$	100	0.98	0.31	330	0.735	0.825	0.65	254	247	0.56	0.665	414	152
1a	Image orthicon, 5820	34	0.98	1.0	37.7	0.735	0.825	2.1	26.8	247	0.56	0.665	43.5	152
1b	Image orthicon, 5826	66	0.98	1.0	67.4	0.735	0.825	2.1	52	247	0.56	0.665	84.5	152
1c	Image orthicon, high-definition	120	0.98	1.0	122.5	0.735	0.825	2.1	94.6	247	0.56	0.665	153.5	152
2	Iconoscope (film pick-up), $I_{\max} = 0.1\ \mu a$	70	0.914	1.0	76.5	0.735	0.66	2.1	69.0	201	0.56	0.4	149	91.6
3	Im. iconoscope, $I_{\max} = 0.1\ \mu a$	70	0.914	0.62	123.5	0.735	0.66	1.3	111.0	201	0.56	0.4	240	91.6
4	Orthicon [C.P.S. Emitron), $I_{\max} = 0.1\ \mu a$	70	0.914	0.31	247	0.735	0.66	0.65	222	201	0.56	0.4	482	91.6
5	Vidicon, 6198, $I_{\max} = 0.45\ \mu a$	315	0.914	0.515	668	0.735	0.66	1.08	600	201	0.56	0.4	1300	91.6
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(5)	(6)	(8)	(9)

Notes:
(1) From Table XVII.
(2) From Table XVII sharp filter, aperture correction 1 ×.
(3) $\dot{\gamma}_v = \dot{\gamma}_r \dot{\gamma}_2 / 2.1$ value at $\hat{B}$ from Tables XIX to XXII.
(4) Signal-to-noise ratio after filter, Eq. (80).
(5) Eq. (81) for $n_r = 490$.
(6) From Figs. 99a or 100a for $N_{e(k)} = 340$, curve 1.
(7) From Tables XIX to XXII at $\hat{B}$.
(8) Eq. (69).
(9) Eq. (68).

Table XXIII. Maximum Signal-to-Deviation Ratios $[R]_{s\ \max}$ of 525-line Television System With $\Delta f = 4.25$ Mc, Transfer Characteristic Curve 1, Fig. 103, and Maximum Aperture Correction.

Curve no.	Type of signal curve	$[R]_{m\ \max}$	N_{e1}	Apt. corr. at N_e	$N_{e(b)} = 265$					$N_{e(b)} = 153$ (Kine. + eye for $d/V = 4$)			
					$\alpha^{\frac{1}{2}}$	$\beta^{\frac{1}{2}}$	γ_s	$[R]_{s\ \max}$	$\bar{N}_{e(s)}$	$\alpha^{\frac{1}{2}}$	$\beta^{\frac{1}{2}}$	$[R]_{s\ \max}$	$\bar{N}_{e(s)}$
0	Light spot scanner, $I_{\max} = 0.01\ \mu a$	100	250	2	1.0	0.735	0.65	210	300	0.74	0.56	372	169
1a	Image orthicon, 5820	34	200	2.5	1.12	0.735	2.1	19.7	336	0.79	0.56	37	180
1b	Image orthicon, 5826	66	200	2.5	1.12	0.735	2.1	38.2	336	0.79	0.56	71	180
1c	Image orthicon, high-definition	120	250	2	1.0	0.735	2.1	78	300	0.74	0.56	138	170
2	Iconoscope (film pickup), $I_{\max} = 0.01\ \mu a$	70	200	2.5	1.15	0.735	2.1	39	346	0.61	0.56	98	140
3	Image iconoscope, $I_{\max} = 0.1\ \mu a$	70	200	2.5	1.15	0.735	1.3	64	346	0.61	0.56	158	140
4	Orthicon (C.P.S. emitron), $I_{\max} = 0.1\ \mu a$	70	200	2.5	1.15	0.735	0.65	127	346	0.61	0.56	315	140
5	Vidicon, 6198, $I_{\max} = 0.45\ \mu a$	315	158	4	1.66	0.735	1.08	239	500	0.84	0.56	620	192
		(1)	(2)	(3)	(4)		(5)	(6)	(7)	(4)		(6)	(7)

Notes:

(1) From Table XXII.
(2) Equivalent passband of camera tubes (approximate values).
(3) Obtained from Fig. 99a for $(N_{e(\psi)}/N_e)_h = N_{e1}/340$ and $\alpha^{\frac{1}{2}} = 0.975$ (to obtain $r_{\bar{\psi}1} r_{\bar{z}} = r_{\bar{z}f}$).
(4) From Fig. 99a or 100a for $N_{e(h)} = 340$ and $N_{e(\psi)} = N_{e(b)}$.
(5) From Table XXII, value at $\hat{B}$.
(6) Eq. (69).
(7) Eq. (68).

Table XXIV. Maximum Signal-to-Deviation Ratios $[R]_{s\,\max}$ of 625-line Theater Television System With $\Delta f = 8$ Mc, Transfer Characteristic Curve 1, Fig. 103, and Maximum Aperture Correction.

Curve no.	Type of signal source	$[R]_{m\,\max}$	Apt. corr. at N_c	$m^{\frac{1}{2}}$	$\dot{\gamma}_v$	$[R]_{3\,\max}$	$N_{e(b)} = 400$, (at screen) $\alpha^{\frac{1}{2}}$	$\beta^{\frac{1}{2}}$	$\dot{\gamma}_v$	$[R]_{s\,\max}$	$\bar{N}_{e(s)}$	$N_{e(b)} = 240$, $(d/V = 2.5)$ $\alpha^{\frac{1}{2}}$	$\beta^{\frac{1}{2}}$	$[R]_{s\,\max}$	$\bar{N}_{e(s)}$
0	Light-spot scanner, $I_{\max} \simeq 0.01\ \mu$	73	4	2.02	0.31	116.5	1.43	0.83	0.65	94.7	665	0.94	0.642	186	338
1b	Image orthicon, 5826	48.1	6	2.76	1.0	17.4	1.9	0.83	2.1	14.5	884	1,18	0.642	30	425
1c	Image orthicon, high-definition	87.5	4	2.02	1.0	43.3	1.43	0.83	2.1	35.1	665	0.94	0.642	69	338
3	Image iconoscope, $I_{\max} = 0.1\ \mu a$	27.1	6	3.57	0.62	12.2	2.26	0.83	1.3	11.1	1050	1.08	0.642	30	388
4	Orthicon (C.P.S. emitron), $I_{\max} =$ 0.1 μa	27.1	6	3.57	0.31	24.5	2.26	0.83	0.65	22.2	1050	1.08	0.642	60	388
5	Vidicon, 6198, $I_{\max} = 0.45\ \mu a$	122	6	3.57	0.515	66.5	2.26	0.83	1.08	60.2	1050	1.08	0.642	163	388
		(1)	(2)		(3)	(4)	(5)	(6)	(3)		(7)	(5)	(6)		(7)

Notes:
(1) Values from Table XXII multiplied by $(4.25/8)^{\frac{1}{2}}$ for curves 0, 1b and 1c; and by $(4.25/8)^{\frac{3}{2}}$ for curves 3, 4 and 5.
(2) Curves 0 and 1c corrected to $\alpha^{\frac{1}{2}} = 0.975$; curves 1b, 3 and 4 corrected to $\alpha^{\frac{1}{2}} = 0.95$; curves 3, 4 and 5 corrected to $\alpha^{\frac{1}{2}} = 0.71$
(3) From Table XXII.
(4) Electrical signal-to-noise ratio after filter, Eq. (80).
(5) From Figure 99a or 100a for $N_{c(h)} = 537$.
(6) Eq. (81) for $n_r = 584$.
(7) Eq. (68) for $(N_{c(h)}n_r)^{\frac{1}{2}} = 560$.

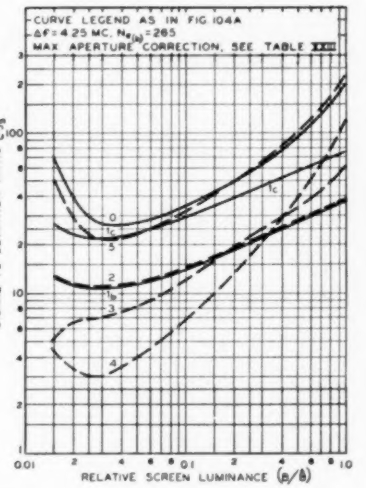


Fig. 105a. Signal-to-deviation ratios at the screen of standard 525-line USA television systems using an average kinescope ($N_{e(b)} = 265$), aperture correction for equal horizontal sine-wave response, and gamma correction to obtain the transfer characteristic 1, Fig. 102.

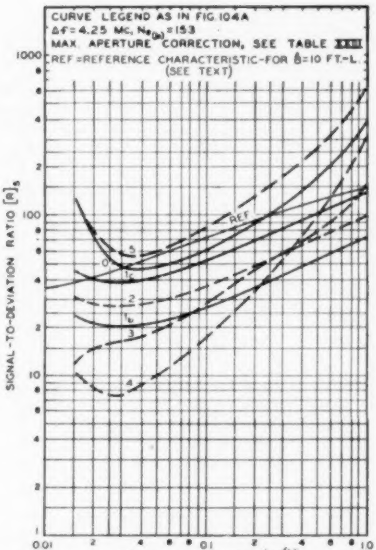


Fig. 105b. Signal-to-deviation ratios in the retinal image for the conditions of Fig. 105a modified by a viewing distance $d = 4V$.

on the abscissa of Fig. 99a and read off the aperture correction required for the desired value $\alpha^{\frac{1}{2}} = m^{\frac{1}{2}} = 0.975$. A tabulation of the values obtained for a standard television channel ($N_{c(h)} = 340$) is given in column 3 of Table XXIII. The various degrees of aperture correction alter the factors $\alpha^{\frac{1}{2}}$ of the system following the point of "noise" insertion as listed in column 4 for the previously used apertures $N_{e(b)} = 265$ and $N_{e(b)} = 153$ following the electrical system. The corresponding $[R]_s$-characteristics shown in Figs. 105a and 105b are based on equal transfer characteristics and equal horizontal response in a standard television channel with $n_r = 490$ and $N_{c(h)} = 340$.

A comparison of the signal-to-deviation characteristics of a standard 35mm motion-picture projection (Fig. 57b, Part II) and television images of similar quality is given in Table XXIV and Figs. 106a, 106b, and 106c. It will be shown in Part IV that a 30-frame television system having $n_s = 625$ lines and a video passband $\Delta f = 8$ mc is adequate to duplicate 35mm motion-picture performance. This performance can be obtained only with high-quality signal sources, maximum aperture correction and high-quality reproducers ($N_{e2} = 400$). The performance of all camera-tube types, however, has been computed for comparison. The $[R]_s$-characteristics Fig. 106a represent conditions at the screen and Figs. 106b and 106c at the retina of the eye for the viewing distances $d = 2.5V$ and $4V$ respectively. The motion-picture characteristic in Fig. 106a is the $[R]_p$-characteristic shown in Fig. 57b of Part II. At a viewing distance $d = 2.5V$ the equivalent passband of the eye is $N_{e(eye)} = 300$ (Eq. (87)). In cascade with the equivalent passband $N_{e(p)} = 370$ of the motion picture, the overall system passband be-

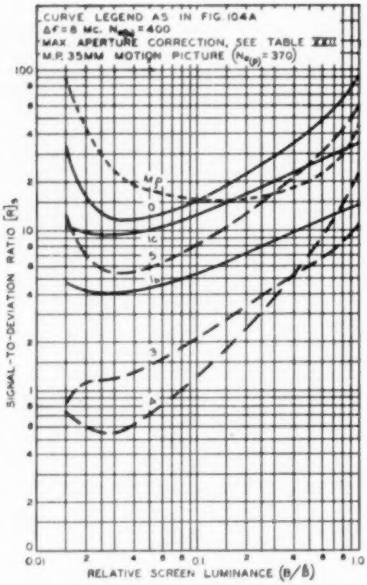


Fig. 106a. Signal-to-deviation ratios at the screens of 35mm motion-picture and 625-line theater-television systems (Δf = 8 mc) having the transfer characteristics in Fig. 102, a television projector with $\bar{N}_{e(b)}$ = 400 and high aperture correction to provide equivalent sharpness (see text).

comes $\bar{N}_{e(s)}$ = 233. The motion-picture characteristic in Fig. 106b is obtained with $[R]_s = [R]_p$ (370/233) and in Fig. 106c with $[R]_s = [R]_p$ (370/188) because in these cases the relative amplitude distribution in the deviation spectrum and the products $[R]_p\bar{N}_{e(s)}$ remain substantially constant (see p. 22, Part II). The characteristics in Fig. 106 show that in the medium and light tone range the motion-picture frames have larger deviations (lower $[R]_s$) than the television systems curves 0, 1c and 5, but that the granularity of the motion picture is lower in the shadow tones.

With increasing viewing distance, the signal-to-deviation characteristic of the aperture-corrected television systems im-

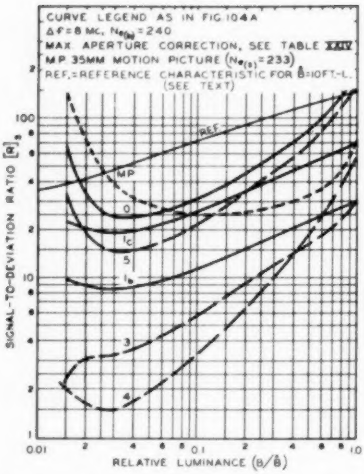


Fig. 106b. Signal-to-deviation ratios in the retinal image for the conditions of Fig. 106a modified by a viewing distance d = 2.5V.

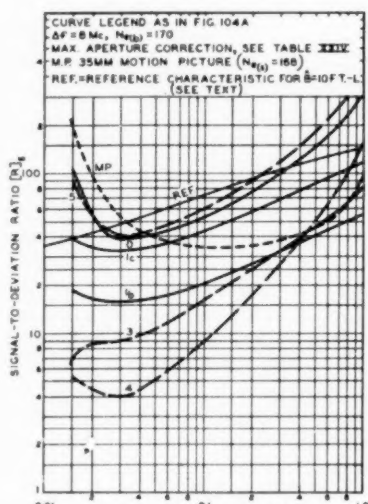


Fig. 106c. Signal-to-deviation ratios in the retinal image for the conditions of Fig. 106a modified by a viewing distance d = 4V.

proves more rapidly than that of the motion picture. It must also be borne in mind that the signal-to-deviation ratios evaluated for the motion picture are values that neglect all defects and scratches which noticeably increase the deviation level in the film projection above the ideal values after relatively few runs, as borne out by measurements of the noise level from the sound track of motion-picture film. There is no parallel degradation in live-television systems, because every showing is a "first" showing. The signal-to-deviation characteristics of the theater-television systems using the high-definition image orthicon (Fig. 95), light-spot scanners, or the type-6198 vidicon are, therefore, satisfactory in comparison with motion pictures. The definition obtained with the type-6198 vidicon, however, is not equivalent to 35mm motion pictures.

3. Equivalent Passband ($\bar{N}_{e(s)}$) and Sine-Wave Amplitudes

Amplitude distribution and N_e-values for the sine-wave spectrum of the deviations in a television frame can be computed accurately from the products of corresponding response factors for the system elements following the noise source.

The sine-wave response of a particular combination of elements can be approximated with good accuracy by one of the normalized characteristics given in this paper. The analysis of the intensity distribution in the vertical coordinate (Eq. (57) and Fig. 70) has shown that the television raster may produce a carrier wave containing a series of sine-wave components with fixed amplitudes. These constant carrier components are not included in the total energy of the deviations. When the deviations originate in electrical elements, the vertical-frequency spectrum is in all cases that of the aperture δ_b following the electrical elements (see section C2). The sine-wave response of theater-television systems (not including camera) is illustrated in Fig. 107. The response factors are by definition the amplitudes obtained with a normalized sine-wave energy input into the theoretical television channel, i.e., for an rms noise input voltage $[\bar{E}]_m = 1$. The equivalent passbands in the horizontal and vertical coordinates have been related to the theoretical passband by bandwidth factors; $N_{e(h)} = \alpha N_c$ and $N_{e(v)} = \beta n_r$ to permit evaluation by normalized characteristics. The equivalent passband ($\bar{N}_{e(s)}$) of the system is computed with Eq. (68) (see Tables XXII to XXIV).† While the response factors in the horizontal and vertical coordinates are independent of one another, the actual amplitudes of the sine-wave flux components of the deviation flux are not, because the total sine-wave deviation energy $P_0 = c^2\bar{N}_e$ is independent of direction. For a normalized deviation "output" energy $P_0 = 1$, the amplitude scale factor is therefore $c = \bar{N}_e^{-\frac{1}{2}}$ for symmetrical apertures, and the amplitude distribution $Y_{(N)} = f(N)$ is obtained by multiplying the response factors r_ψ by the scale factor:

$$Y_{(N)} = r_\psi c = r_\psi(\bar{N}_e)^{-\frac{1}{2}} \qquad (89)$$

Similarly for television systems:

$$\left.\begin{aligned} &Y_{(N)h} = r_{\psi(h)} \qquad c_{(h)} = r_{\psi(h)}(\alpha N_c)^{-\frac{1}{2}} \\ &\text{and} \\ &Y_{(N)v} = r_{\psi(v)}c_{(v)} = r_{\psi(v)}(\beta n_r)^{-\frac{1}{2}} \end{aligned}\right\} \qquad (90)$$

The *relative* amplitude characteristics corresponding to Fig. 107 are shown in Fig. 108. The characteristic of the 35mm

† Because of aperture correction the value $\bar{N}_{e(s)}$ does exceed the theoretical value $\bar{N}_{e(m)}$ considerably for the condition $N_{e(h)} = 400$ in Table XXIV. This abnormal condition exists for deviations only and it should be remembered that an equivalent passband is by definition a "flat" passband which would contain the same total deviation energy. The system response to sine-wave components in picture signals is normal, because it includes the decreasing response of the camera tube.

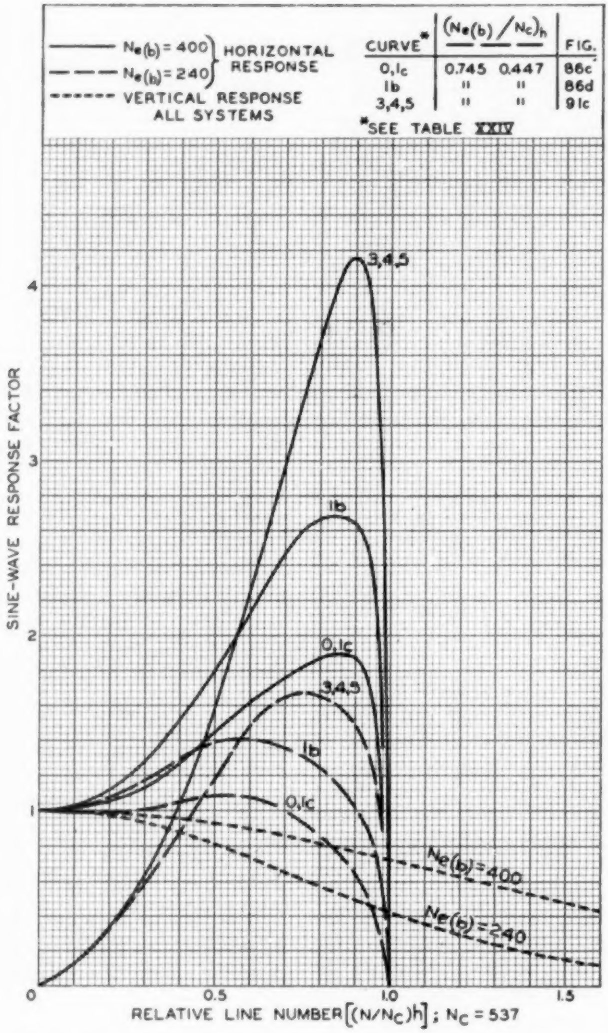


Fig. 107. Sine-wave response factors of theater-television and motion-picture systems for the conditions of Figs. 106a and 106b.

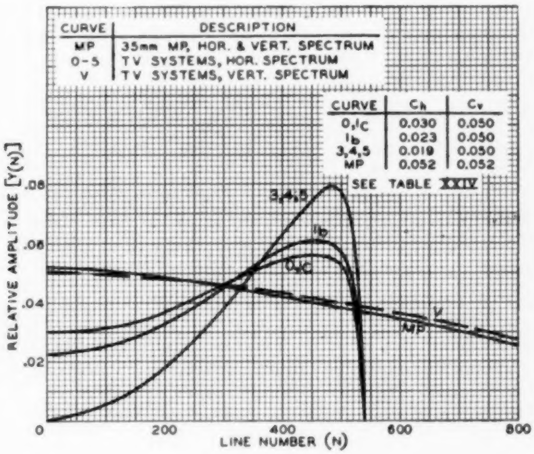


Fig. 108a. Relative amplitudes of sine-wave spectra for equal-energy signals and deviations at the screen of theater-television and motion-picture systems.

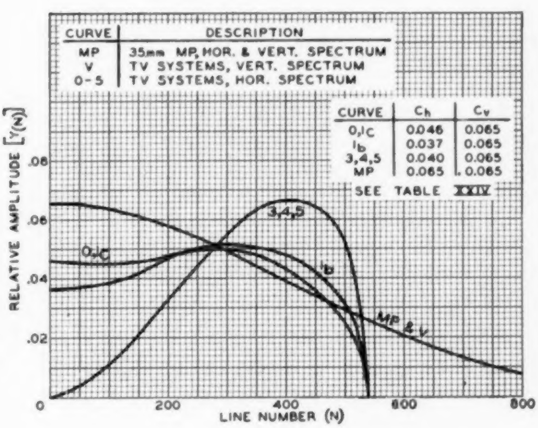


Fig. 108b. Relative amplitudes of sine-wave spectra for equal-energy signals and deviations at a viewing distance $d = 2.5V$ from the screen of theater-television and motion-picture systems.

motion picture in Fig. 108a is that of Fig. 59, Part II, normalized for $P_0 = 1$ by multiplication with $c = 370^{-\frac{1}{2}} = 0.0518$, and by $c = 233^{-\frac{1}{2}} = 0.0653$ for Fig. 108b, which represents conditions at the retina for a viewing distance $d = 2.5V$.

The visual appearance of the grain structures in motion-picture and television frames is indicated by the amplitude spectra (Fig. 108) for equal signal-to-deviation ratios. The vertical spectra are substantially identical and the preponderance of low frequencies indicates a soft grain structure. The horizontal television spectra for "flat" channel deviations (0, 1*b*, 1*c*) have a somewhat smaller and sharper appearing grain size. The "peaked" channel deviations (3, 4, 5) containing no low frequencies and having maximum energy at a fairly high line number (N = 400 to 500), have a smaller and more uniform appearing grain size.

This interpretation of the amplitude spectra may be compared with the grain

Figure 109 is on plate pages 118 and 119.

structure photographs shown in Fig. 109 which were taken under somewhat similar conditions in a 4.5-mc system for the purpose of measuring the deviation ratio in an image frame by sampling with a physical aperture. The linear dimension of the samples in Fig. 109 is approximately one-fourteenth of a picture frame. The samples A, B and C are photographs of "peaked" channel, "flat" channel, and 35mm motion-picture grain structures respectively. In the top row (index 1) are single-frame grain structures obtained with small apertures δ_b showing the raster line structure of the television samples A and B. The middle row (2) illustrates the condition for a larger aperture δ_b for all 3 cases. This aperture was given a value to produce a "flat field" in the television frames and equal the spot size of the supercinephor lens for C2. Note the longer grain size in the vertical direction of A2 which is evidence of the flat-frequency spectrum across the raster even from a peaked "noise" source, which causes positive- and negative-grain doublets in the horizontal coordinate due to the absence of low frequencies and the differentiated pulse shape shown in Fig. 93. The samples A3 and B3 show the effect of superimposing the grain structures of six television frames by a photographic exposure of $\frac{1}{5}$ sec. The deviations were increased in magnitude to show more clearly that the grain doublets have practically disappeared in A3 due to random superposition.

4. Discussion of Results

Examination of the various signal-to-deviation characteristics shows clearly that the theoretical signal-to-noise ratios $[R]_{m\ max}$ (Table XVII) is not an adequate measure of camera-tube performance. It is evident from Tables XXII and XXIII that the electrical signal-to-noise ratios $[R]_{3\ max}$ which can be measured in the video-transmission link, may also differ substantially from the theoretical value $[R]_{m\ max}$, because for comparable definition the sine-wave response of the camera tube is reflected in the degree of aperture correction and alters the sine-wave amplitudes in the frequency spectrum of the deviations.

Aperture correction increases the noise level by a factor which is larger for peaked-channel noise than for flat-channel noise, as illustrated by the value of the electrical factor $m^{\frac{1}{2}}$ in Table XXIV for conditions 1b and 3, for example. The filtering action of succeeding apertures has an opposite effect, reducing the deviation level $(1/[R]_r)$ and granularity of the retinal image by a larger factor for peaked-channel noise than for flat-channel noise. These factors are given by the ratio of corresponding factors $\alpha^{\frac{1}{2}}$ which, according to Table XXII, is $0.665/0.4 = 1.66$ in favor of peaked-channel noise without aperture correction and at a viewing distance $d = 4V$ from a standard 525-line television image.† When moderate aperture correction is used the ratio decreases (see Table XXIII) and with high aperture correction it approaches unity (see Table XXIV) and may even reverse. *It therefore appears desirable to specify the entire signal-to-deviation characteristic in the retinal image for a given viewing distance.* To judge the entire characteristic it is necessary to establish a *reference characteristic based on the perception of random deviations* as a function of luminance.

Subjective observations as well as fun-

† This value is considerably lower than the ratio given in the author's earlier paper.[3] The earlier values are in error because they are ratios of bandwidth factors (α) rather than factors $(\alpha^{\frac{1}{2}})$.

damental considerations[6,7] indicate that the visual perception of fine detail and granularity is limited at low luminance values by random fluctuations in the visual process and at medium and high luminance values by the aperture response of the optical system of the eye (see, for example, Fig. 83). From an objective point of view, perception of fluctuations from an external source (image) in the low luminance range occurs when the total deviation from both external and internal sources exceeds the internal deviations of the visual process by a barely perceptible amount which can be assumed related to a visual sensation unit. When the optical and photoelectric characteristics of the eye are known, the ratio of the two deviations may be calculated as a function of luminance by the method outlined in this paper. The evaluation of an analog system for the visual process based on data from subjective observations appears possible and of considerable value for an objective analysis. This will be discussed in Part IV.

For the present it is sufficient to refer to such observations, which indicate that the signal-to-deviation ratio in an external or retinal image required to give threshold visibility, is nearly constant for luminance values (B) above 10 ft-L, and decreases for values less than 10 ft-L. The luminance values of motion-picture and theater-television projections fall into this lower range. For use as a reference standard the exact vertical location of the threshold curve for the eye is not important, unless one is specifically interested in threshold values.† Shape and approximate location of the reference characteristic are shown in Figs. 106b and 106c, for a highlight brightness $\hat{B}$ = 10 ft-L. It is noted that the image-orthicon curves 1b and 1c have a fairly uniform vertical distance to the reference characteristic, which means that perception of their grain structure is fairly uniform, decreasing towards the ends of the range. The shape of the motion-picture characteristic (MP) indicates that its grain structure will appear most perceptible at $B/\hat{B} \simeq 0.4$ but is invisible in the deep shadow tones.

Referring now particularly to Fig. 106b which represents conditions at the close viewing distance of 2.5 times the vertical screen dimension, it can be seen that graininess in the systems represented by curves 5 and MP will be perceived with similar intensities but in a different part of the luminance range. Similarly, when comparing curves 1_c and MP, and it is evident that the motion picture will appear more grainy in the upper half of the tone range than the television picture which exhibits a nearly uniform graininess over the entire range. At the more normal viewing distance of $d = 4V$ represented by Fig. 106c, the characteristic of the motion picture is positioned for the most part much farther below the threshold-reference characteristic than those of the television systems 0, 5 and 1c, which now appear in general less grainy than the motion picture. Considering furthermore that the motion-picture characteristic is representative of an ideally "clean" film it can be concluded that the graininess of theater-television images, such as are represented by curves 0, 1c and 5 in particular, will compare favorably with that of 35mm motion pictures.

The evaluation of deviations of electrical origin in television frames has shown that television systems may be designed to have a performance substantially equal to a 35mm motion-picture system. Because of the similar frame rate, the storage factor s and signal-to-fluctuation ratios in "live" television pictures are not materially different from those of motion pictures.

† It is noted that observations on the perception of fluctuations in television pictures made at luminance values above 10 ft-L are not likely to apply directly to the lower luminance values of theater television and motion pictures.

A camera tube with adequate signal output and definition such as the experimental high-definition image orthicon (curve 1c in Fig. 106, and Table XXII is required for a theater-television system having a granularity comparable to that of a 35mm motion picture using plus X) negative and fine-grain positive film (1302). The theoretical value $[R]_{m\ max}$ at the source for this type of camera tube corresponds to an electrical noise level of −38.8 db, or −41.3 db including synchronizing signals. The noise level in the video-transmission system (corresponding to $[R]_3 = 43.4$) is −32.7 db, or −35.2 db including synchronizing signals. To prevent impairment of this performance, the noise level of the transmission system itself should be approximately 6 db better, or both the transmission system and the camera tube should have noise levels 3 db lower than stated above.

A more accurate statement can be made when the amplitude distribution in the frequency spectrum of the additive noise is known. Statistical tests of signal-to-deviation ratios by the sampling of television grain-structure photographs on 4 × 5-in. film have been in good agreement with computed values. The above method has also been applied to compute the noise levels reported by Pierre Mertz in two publications.[8,9] In view of the estimates which had to be made for a number of unspecified system constants the calculated values appeared to be in satisfactory agreement with the reported values.

Many relations between apertures and their sine-wave response characteristics as well as characteristics of vision have only been indicated and will be discussed in more detail in Part IV of this paper.

References

1. Pierre Mertz and T. Gray, "The theory of scanning and its relation to the characteristics of the transmitting signal in telephotography and Television," *Bell Sys. Tech. J., 13:* p. 464, 1934.
2. I. C. Gardner, "A new resolving power test chart," (abstract), *J. Opt. Soc. Am., 40:* 257, Apr. 1950.
3. O. H. Schade, "Electro-optical characteristics of television systems, Part III—Electro-optical characteristics of camera systems," *RCA Rev., 9:* 490–530, Sept. 1948.
4. P. Schagen, H. Bruining and J. C. Francken, "The image iconoscope—a camera tube for television," *Philips Tech. Rev., 13:* 119–133, May 1951 (abstracted in *Jour. SMPTE, 58:* 501–514, June 1952).
5. W. A. Harris, "Fluctuations in vacuum tube amplifiers," *RCA Rev., 5:* 505–525, Apr. 1941; *ibid., 6:* 114–124, July 1941.
6. O. H. Schade, "Electro-optical characteristics of television systems, Part IV—Correlation and evaluation of electro-optical characteristics of imaging systems," *RCA Rev., 9:* 653–686, Dec. 1948.
7. A. Rose, "Television pickup tubes and the problem of vision," *Advances in Electronics, I:* 133–166, Academic Press, New York, N.Y., 1948.
8. Pierre Mertz, "Perception of television random noise," *Jour. SMPTE, 54:* 8–34, Jan. 1950.
9. Pierre Mertz, "Data on random noise requirements for theater television," *Jour. SMPTE, 57:* 89–107 Aug. 1951.

Photographic Instrumentation of Timing Systems

By A. M. ERICKSON

Time-action marking at film speeds from 2000 to 8000 frames/sec and some of the circuit requirements which must be met to obtain clear edge marks on motion-picture film are discussed.

Photographic timing has become necessary in the field of instrumentation. Primarily time is correlated with an action on motion-picture film. It gives facts about that action which otherwise cannot be obtained. For instance, timing on motion-picture film has been used to study velocity, acceleration, oscillation (pitch and yaw), vibration and position of projectiles in flight. The same photographic system has been used to gather data about explosive trains, shock waves and a variety of other high-speed action phenomena.

Under conditions which dictate the use of high-speed cameras we have found that neon gas ionization is one of the most serviceable methods of film marking. It has been chosen in preference to argon gas ionization, spark gaps and field-of-view devices for general use at the Naval Ordnance Laboratory for the following reasons: (a) neon will mark color film with good contrast (this is not so for argon gas); (b) neon is not affected by atmospheric conditions as in the case of spark gaps, and is relatively simple from a voltage standpoint; (c) field-of-view timers consume valuable picture space and are subject to focus and lighting conditions which are not always the same as that of the subject.

The Naval Ordnance Laboratory has fitted many of its cameras with neon timing lights and has attempted to standardize on the NE-51 bulb, a recent addition to the neon family.

To excite neon gas for clear edge marking it is necessary to produce a pulse of at least 90 v. A duration of not less than 8 μsec and the power to maintain voltage during ionization is also necessary. The "work horse" timing system (shown in Figs. 1 and 2) more than meets these minimum requirements. It consists of three units, an oscillator, a pulse generator and a six-channel cathode follower.

The oscillator is a battery-powered fork with good stability which delivers

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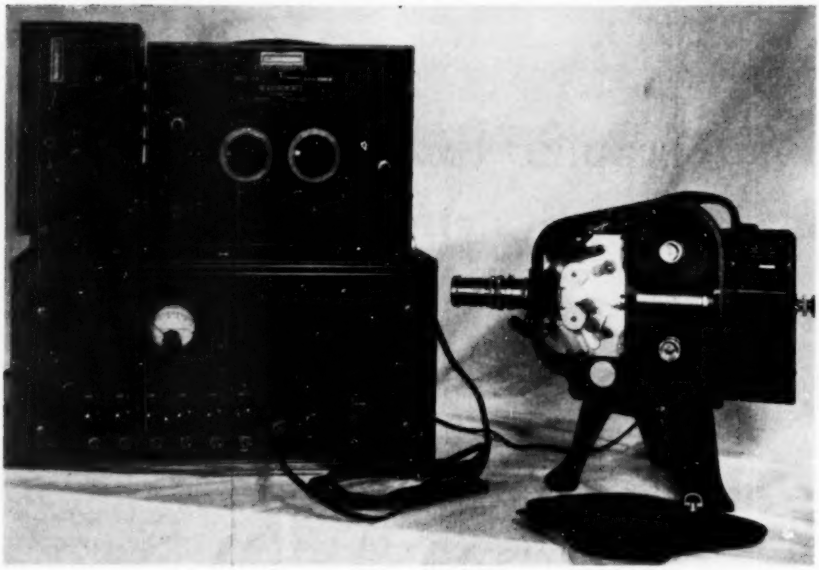


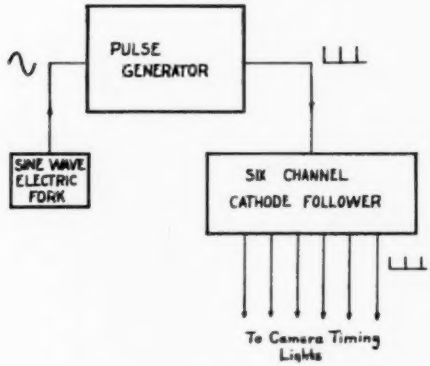
Fig. 1. Pulse timing system and neon timing light mounted on upper sprocket clamp of an Eastman High-Speed Camera.

about 25 v to a high-impedance load. Its output is used only to control the repetition rate of the pulse and is dependable under a variety of field conditions.

The a-c powered pulse generator, which is controlled by a stable-frequency source, is independent of voltage and frequency variations of the power line. For operation of only one camera this generator is connected directly to the camera marking light.

To time up to six cameras a six-channel cathode-follower amplifier system is used. This unit when driven directly by the pulse generator develops marking pulses on six separate circuits. Each light is given its own individual circuit mainly for insurance. It has been found that neon bulbs exhibit high firing potentials after considerable use, some measuring above 100 v, as compared with 75 v for new bulbs. If several used bulbs are placed across the same circuit, and the combined load limits peak-pulse voltage to 90 or 100 v, an old bulb may not fire, or it may fire erratically and give false timing information which is more detrimental than no timing at all. Many field tests are conducted specifically for the photographic results. The total cost of test operations may range from $100 to $40,000 a day with complete destruction of the ordnance material under test. In the face of such expensive operations it is unwise to design borderline features into instruments which add to this expense.

Each cathode-follower output circuit is equipped with a current-meter switch and a variable-series resistance. Exposure current, a predetermined value of approximately 1 ma (average), is adjusted by varying the series resistance. This provides an indication of proper intensity regardless of line length, and proof that the exposure light is functioning. This facility of remote test and exposure adjustment is valuable in



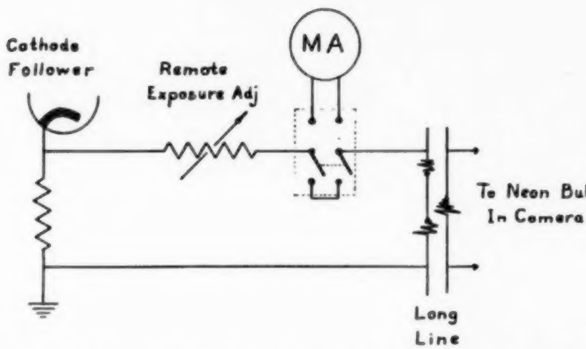


Fig. 2. (Above) Pulse timing system. (Below) Detail of the pulse timer output circuit.

both time and labor to the photographer when his cameras are spread over a long firing range or at the top of range towers.

In addition to time marking, some instrumentation requires "start-action marks" on the film to indicate when an event takes place, such as the breaking of a wire, the closing of a firing key, or the attainment of certain water pressures. When action begins with the firing of a detonator by electrical means, it is better to tap the firing circuit for start information if it is possible. Any electrical connection made to firing circuits other than those necessary to fire the detonator are considered a safety hazard and precautions must be taken to eliminate prematures. The circuit shown in Fig. 3 will not only provide a pulse of the proper impedance and polarity but will fire the detonator and under certain circumstances provide bias to gate a timing circuit closed until start marking has taken place.

When a double-pole relay is used with a firing circuit over one set of contacts, and a pulse circuit over the other, error will always result when trying to close two sets of contacts at the same time. This error is usually of the order of a few milliseconds even though both sets of contacts are on the same relay, and cannot be depended upon for accurate or close timing. The Naval Ordnance Laboratory system

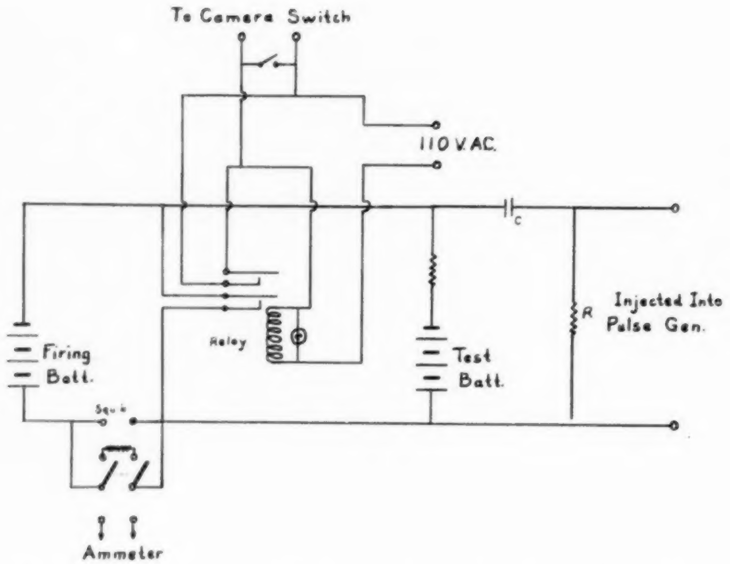


Fig. 3. Diagram of start-marking system for marking motion-picture film at instant firing key is closed.

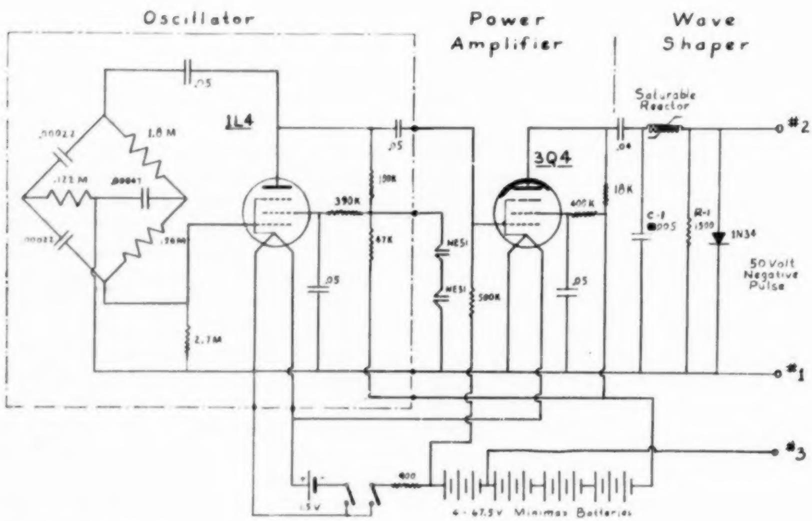


Fig. 4. Portable battery-powered pulse timer designed for field use, incorporating magnetic amplifier principles to shape the timing pulse.

uses one set of contacts to close both circuits. In stand-by condition two batteries are connected in parallel through the detonator and a large resistance. A charging or discharging current will flow between two identical batteries until both batteries are of the same terminal voltage. Even the most sensitive primers will stand 100 μa without damage to the squib wire. A microammeter is available to test any lack of voltage balance prior to connecting the primers in the circuit.

The start-mark circuit is connected to the grid of a voltage-amplifier stage in the pulse generator as shown in Fig. 2. It delivers a pulse with a delay time governed by R and C of Fig. 3. This results in a film which contains a start mark injected into the regular timing pulses. A disadvantage from a data reduction point of view is that interpolation is necessary to determine the time interval between the start mark and the next timing mark.

One of the main sources of trouble in field instrumentation originates from field power supplies. When these supplies are furnishing power to both high-speed cameras and timing equipment, a peak load caused by camera "start up" momentarily disables the timing equipment and results in a loss of timing marks during the action period. A completely battery-powered timer is useful under these conditions. The timer must be stable and should develop enough power to meet the previously mentioned requirements. These features are incorporated into a new design which uses magnetic-amplifier principles for wave shaping (see Fig. 4).

The circuit generates a stable sine wave, power-amplifies this sine wave and converts the wave into a pulse. The oscillator is an RC-controlled feedback circuit with good stability. It has been constructed as a plug-in unit to change frequency by changing the entire oscillator. The second stage operates as a class "A" amplifier and develops power to drive the pulse-shaping circuit. The shaping is done by passing the sine-wave current through a saturable reactor. As the core is driven into saturation the reactor loses its inductance and transfers its inductive voltage drop to the series resistance R-1. The sudden decrease in load resistance causes condenser C-1 to "dump" its excessive charge through R-1 and causes a still further increase in voltage. The net result is sharp pulses of about 50 v developed across a relatively low impedance. These pulses plus a d-c bias make up enough voltage to fire neon timing lights. The pulses appear across terminals #1 and #2. The pulse and the bias may be obtained without additional components by connecting the marking bulb across terminals #2 and #3. This places the first battery of the "B" supply in series aiding with the output pulse.

Timing marks without an associated picture can also be useful under certain conditions. In the development of an arming vane for a missile, instrumentation was needed to determine angular velocity and acceleration of the vane under flight conditions. The problem was solved by the simplest kind of pulsing circuit (see Figs. 5 and 6). The recorder consists of a photographic film rotated by the arming vane. As the film turns, a pulse-driven exposure light marks the perimeter of a disk to give time-motion characteristics at the rate of approximately one mark every 25 msec. With a 100:1 step-down gear ratio, and an assumed vane speed of 6000 rpm, the film disk was estimated to make not more than 1 rps. This spaces the timing marks about 9° apart when the vane is rotating at its maximum estimated speed.

"Start" and "stop" switches are placed on the outside of the missile, while all other components are fitted in the booster cavity. One switch puts the circuit into operation just before launching, and the other disables it

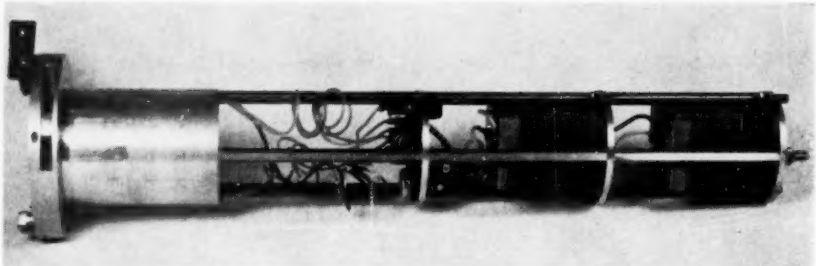


Fig. 5. Rocket arming-vane timer which mounts in a rocket case. The timer marks a rotating disk of film to record the velocity and acceleration of the arming vane during flight. Left to right: film-disk housing; circuit shelf; batteries.

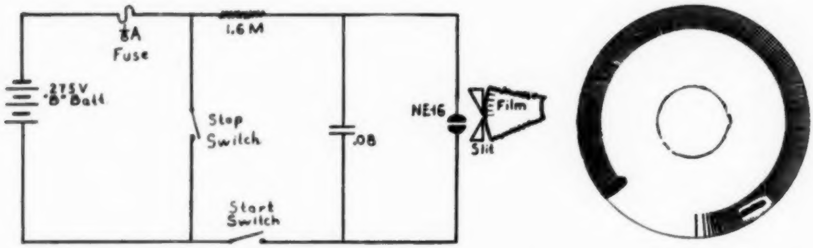


Fig. 6. (Left) Schematic of the basic RC-pulsing circuit installed in the rocket booster cavity. Start and stop switches are mounted on the outside of the rocket case. (Right) Diagram of time-recorder test film; one space equal to 23.8 msec.

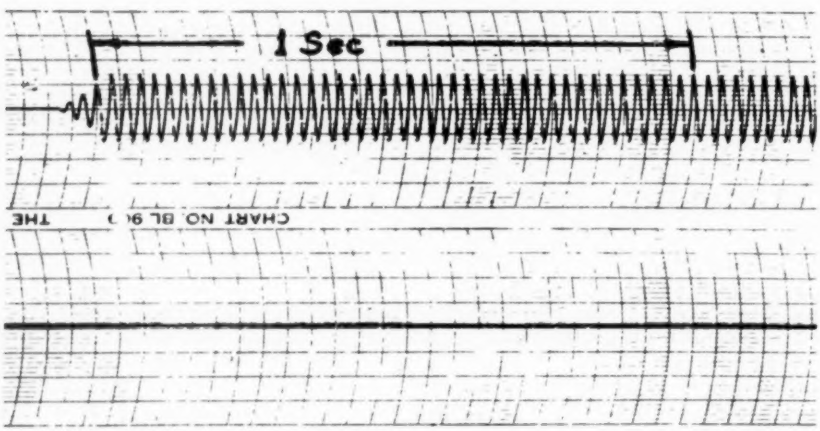


Fig. 7. Photograph of a permanent frequency record made by connecting a Brush Pen Recorder across the battery terminals of Fig. 6. This record is made just prior to rocket launching. Paper speed, 5 in./sec; pulse rate, 42/sec.

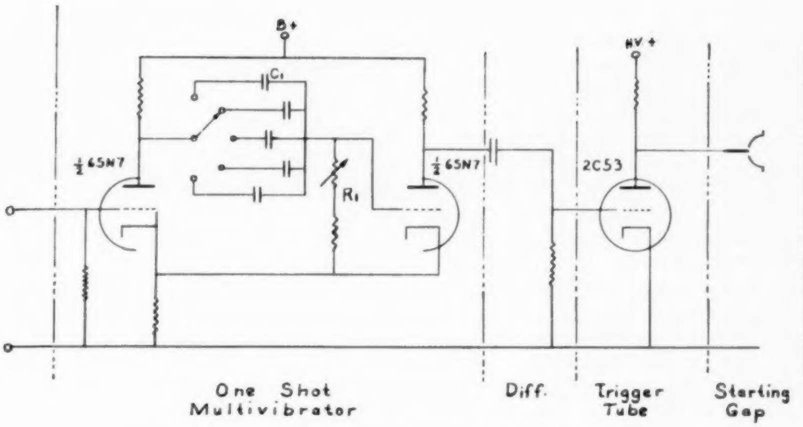


Fig. 8. Diagram of a delay timer designed to trigger photographic spark stations in a ballistics range.

during flight after the record has been taken. Although the system is used at slow film speeds, it can have application in high-speed work if the pulse rate is increased. The waveshape is not a pure pulse, in the sense that it has both a steep rise and fall, but its firing characteristics are such that the lamp receives a maximum current at the instant of ionization and decreases at the RC discharge rate until lamp-extinction voltage is reached. This results in maximum exposure at the leading edge with a fading trail behind it, and furnishes a sharp edge as a reference point on each mark.

The frequency of this generator is dependent upon the characteristics of every component in the circuit and stray capacity of the circuit to ground. Frequency measurements were made by amplifying voltage-notches appearing directly across the battery terminals. Connection to any other point in the circuit gave erroneous readings because of added load or wiring capacity of the measuring equipment. Amplified-voltage notches are recorded as shown in Fig. 7 on a Brush Pen Recorder just prior to launching. This provides a permanent frequency record for data reduction.

The completed unit was tested in the simulation laboratory at an acceleration of 25 gravitational units. This more than exceeded acceleration forces experienced by the unit under launching conditions. No noticeable change in fundamental frequency was measured after the "G" test.

Timing circuits are quite useful in ballistics-range work to trigger microsecond spark lights in photographic stations along a range. An antenna or pickup unit placed slightly ahead of each photographic station senses the passage of a projectile and fires a spark-light source down range to obtain a shadowgraph of the projectile as it passes through the station.

In order to do this an electronic delay timer is necessary to receive the sensing information, hold it for a predetermined period of time, and then emit a signal to fire the spark light. A timer which will perform these tasks is shown in Fig. 8. The first part of the circuit forms an oscillator which reacts only when it receives the "sensing" signal. It is a "one-shot" multivibrator and

has most of its application in radar as a gating or pulsing circuit. The delay time is dependent upon values of RC-coupling components which have been made variable in this circuit to cover the range of delays needed to match projectile velocity.

A missile traveling at 3000 fps takes about 660 μsec to move 2 ft between the sensing antenna and the photographic plate. The sensing antenna immediately pulses the delay circuit to start it timing. The one-shot multivibrator, 610 μsec later, sends a pulse to the trigger tube which has a normal delay of approximately 50 μsec. Together the two delays make up a required total of 660 μsec and fires the main spark light just as the projectile is in position for exposure. The trigger tube in a stand-by condition is drawing its maximum current and holds the auxiliary spark-gap voltage to a minimum. Application of the pulse causes the tube to cut off and allows full-supply voltage to reach the auxiliary gap and fire the main discharge gap.

This high-voltage type of circuit can easily be adapted to function as a start-marking system in high-speed motion-picture cameras. It can be used by placing the spark gap in a camera as an auxiliary to the regular timing light, or it can be connected to the camera frame on one side and the spark allowed to jump to one of the leads of a neon-bulb marking light. This method of start marking does not load the regular timing circuit and can delay marking action for convenience in data reduction or for correlation with other camera records taken of the same action. Also it can be used as the regular timing system to furnish both timing marks and start marks. If a fixed bias instead of a pulse is applied to the circuit at the instant of starting, the film will receive a series of marks spaced in time according to the delay time of the circuits. Data reduction still depends upon a measurement ahead of the first timing mark to find the start mark because the delay timer receives the start information but does not give it out for one cycle.

Discussion

Robert D. Shoberg (White Sands Proving Gd.): I assume you had trouble firing the NE-51 lamp in total darkness. How did you overcome that?

Mr. Erickson: There was no trouble at all as long as we exceeded the firing potential. The regular firing potential of a new bulb is around 75 v. In darkness I don't know what it is. We usually apply about 125 v across a circuit impedance of not more than 1000 ohm.

Mr. Shoberg: We tried that, and had a lot of trouble. Finally we discarded the equipment we were using and put in the Fastax timing system, using an NE-51 lamp.

Mr. Erickson: We have had absolutely no trouble in firing as long as we get above 125 v. An old bulb, remember, will have an increase in firing potential.

Mr. Shoberg: We aged the lamps.

Mr. Erickson: How much power did you use? What kind of circuit did you use to drive it?

Mr. Shoberg: Up to 125 v. We have a very elaborate timing system there, but we ran into the same problems you did. We checked before we ran and everything was going fine. We opened the door of the camera and the lamp was not glowing. We closed the door and made the test — and the film came out blank. The lamp would not start in total darkness at the same voltage it would in the dark.

Mr. Erickson: We have had no trouble.

Mr. Shoberg: You solved the problem by increasing the voltage on the lamp?

Mr. Erickson: Yes. That takes care of it every time.

Mr. Shoberg: It was not practical for us to increase the voltage to that extent so we substituted the NE-66 lamp for the NE-51 lamp. This eliminated our trouble as the NE-66 fires at considerable lower voltage than the NE-51.

Gerald Doughty (*Aberdeen Proving Gd.*): We ran into the same thing. We are using about 65 v d-c bias, with a pulse about 22-μsec duration and 120-v amplitude above bias. The bias serves to keep the bulbs ionized without producing enough light to affect the film traveling at low speeds. Failures of time records practically disappeared. Line-voltage drop due to heavy current loads from camera runs affects this system less than any other we have tried. Bulb life is about 10-min operating time, or approximately 200 Fastax runs.

Mr. Erickson: Regardless of the pulse height?

Mr. Doughty: That is right. We have no trouble from film fogging. The bulbs do get old, and sometimes too old before we change them. But generally they work pretty well.

Mr. Erickson: I don't think we have ever had a bulb fail because of its old age.

Major P. Naslin (*French Laboratory of Armaments*): Would it be possible to make your vibrator-timer insensitive to a very intensive discharge, say 200 wsec within one μsec, which involves very high terms in the order of several thousands.

Mr. Erickson: I don't know what you mean by making it insensitive. Do you mean in the proximity?

Major Naslin: From being triggered.

Mr. Erickson: The idea is to have the timer not trigger when this high current is flowing?

Major Naslin: Nearby.

Mr. Erickson: If it reaches the circuit, it is bound to make the multi-vibrator operate. If you make the input impedance of that circuit low enough, regardless of what this other thing is doing, it won't affect the vibrator, because it responds only to the bias or signal on the first stage. If this bias is raised high enough, the circuit will go into oscillation.

Major Naslin: Have you done it?

Mr. Erickson: Yes, I have. When we were designing this equipment for the Naval Ordnance Laboratory pressured range, the circuit that I showed you (Fig. 8) was considered in the final photographic station. This photographic station setup required the projectile to be charged by a 20,000-v source, and there was a lot of high voltage around near the trigger circuit. We had a common feed source for the high voltage which goes down the range to charge each of the spark-light condenser units also located near the trigger circuit. The discharge of the first spark light, which is a sudden drain and a very high current flow, can affect the sensing antenna on the following station and make it start timing before it is supposed to. We overcame that by merely decreasing the impedance of the circuit being affected. Of course, proper shielding and grounding are necessary.

Follow-up of the Discussion

(*Submitted by the author, April 30, 1953*): In answer to questions about firing potentials the author has conducted a series of tests on 10 NE-51 neon bulbs picked at random. They were placed in a lighted room and individually connected to a d-c voltage with a time constant of 10 sec, that is, 10 sec were required to raise the voltage from 0 to 150 v. Firing potentials for the bulbs ranged from 70 to 76.5 (see Table I).

Table I. Firing-Potential Data Taken on 10 New NE-51 Neon Bulbs (Firing-Potential in Volts).

Bulb No.	1	2	3	4	5	6	7	8	9	10
Daylight	75.0	71.5	72.0	81.0	70.5	71.5	76.5	74.0	74.5	73.0
3 min dark	78.5	81.0	74.5	93.5	90.5	83.5	91.0	79.5	84.0	81.0
24 hr dark	80.0	120.0	125.5	107.0	115.0	117.0	124.0	150+	150+	78.5
3 month dark	99.0	95.0	113.0	105.0	98.0	125.0	90.0	72.0	100.0	90.0
2d try	77.0	73.0	78.0	86.0	72.5	81.0	77.0	72.5	75.0	75.0

After 3 min of darkness the same bulbs exhibited ignition potentials between 78.5 and 93.5 v. After 24 hr of darkness two bulbs failed to fire with up to 150 v. on the first try. The remaining eight bulbs fired between 78.5 and 125.5 v. The two that did not fire broke down at 74.0 v and 109.5 v on the second try. After 3 months of darkness the firing potentials ranged from 72 v to 125 v with no failures. Firing all bulbs the second time decreased the range from 72.5 to 86 v.

Some conclusions can be drawn from these tests: (1) NE-51 bulbs are light sensitive; (2) firing potentials are generally higher in the dark than they are in the light; (3) successive application of voltage causes a random decrease in firing potential with a lower limit being the daylight-firing voltage of that specific bulb; and (4) for start-marking action a pulse in excess of 150 v must be applied for reliable results.

Contrary to popular belief, a pulse generator designed to drive neon timing lights must have the characteristics of a power circuit, not just voltage amplification. A timing light represents a changing load according to its conditions. When fired it represents a very low resistance and the driving circuit must be designed to deliver ample current through this low resistance and still maintain pulse voltage in excess of bulb-firing voltage.

Therefore the generator output should be of the cathode-follower type, rather than a plate-loaded circuit. Power tubes such as the 6L6, 6V6, 6Y6 and 6AS7 with proper circuit connections will solve most timing-light problems.

Discussion of NE-51 Lamp

(*Prepared by H. M. Ferree, General Electric Co., Nela Park, Cleveland, May 7, 1953*): It has long been known that glow lamps such as the NE-51 do have a definite "dark effect." When the lamp must be enclosed in a light-tight enclosure such as a camera, the starting voltage of the lamp may be increased as much as 20 to 50 v, d-c.

The test data presented by Mr. Erickson agree reasonably well with our experience, and the solution he offers, namely increasing the applied potential well beyond the normal starting voltage, has in most cases proven to be the simplest and most satisfactory.

Also, the time required for ionization is reduced as the voltage in excess of normal starting is increased. In some applications this may be a determining factor.

As Mr. Erickson points out, the starting voltage of a glow lamp increases with age. Therefore, where there are no other limiting conditions on the applied voltage, voltages in excess of the 150 he mentions might be used to extend the usefulness of the lamp.

The M-45 Tracking Camera Mount

By MYRON A. BONDELID

A new, versatile tracking camera mount is described. This instrument was developed to solve certain problems in ballistic data-gathering activities. Performance and operational characteristics of the mount, camera types and uses, lenses, communication, orientation, timing and power requirements are also discussed. The tracking camera mount is a completely independent unit, supplying its own power, and capable of negotiating heavy sand.

At the U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif., a new, versatile tracking camera mount has been developed to solve certain problems known as "attitude" in ballistic data-gathering activities and to provide an easy method to track fast-moving objects.

Testing of rockets and guided missiles must be done under dynamic conditions in which the component is allowed to function under normal environmental conditions. The recording of the necessary test data becomes a difficult task under these conditions since no direct mechanical contact with the test object is possible when it is in free flight.

Bell & Howell Eyemos and Superspeed Cameras comprised the bulk of the early photographic recording test equipment, but it was realized early that the exacting demands required of the data recorded left much to be desired. As this was a special need, little equipment could be utilized as manufactured, and physicists, engineers and photographers pooled their knowledge and experience to adapt or devise instruments that could better meet the rigid requirements of determining trajectory, velocity, acceleration, attitude and other data necessary to evaluate scientifically the performance of rockets and missiles under test.

Trajectory, velocity and acceleration are determined by the Askania Cinetheodolites and Bowen Ribbon-Frame Cameras. Attitude is often determined from the Askania, but because of image size, quality and frame rate this is usually insufficient. Therefore attitude, which

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(This paper was received on April 3, 1953.)

This paper is published for information purposes only. It does not represent the official views or final judgment of the Naval Ordnance Test Station, and the Station assumes no responsibility for action taken on the basis of its contents. The M-45 Tracking Camera Mount has not yet been fully developed and several changes mentioned in this report might occur differently in the final form. It is being developed under Task Assignment No. TP 872-H.

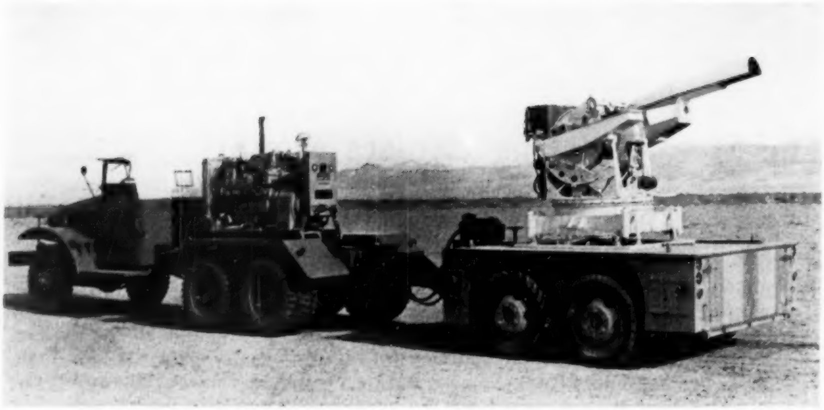

Fig. 1. The M-45 Tracking Camera Mount powered by a 20-kw 3-phase 208-v a-c diesel generator located on the prime mover (*Official Photograph,* U.S. Navy).

includes pitch, yaw and roll, missile-booster separation, off-range deflection, launching, time of flight and detailed motion are usually determined from Mitchell, Fastax, or other high-speed cameras.

A basic approach to the problem of measuring attitude is to take photographs of the missile from at least two positions with motion-picture cameras equipped with long focal-length lenses so that the pictures will be large and easily measured. The apparent angle of the missile with respect to each camera reference system is measured and these data are then mathematically converted to attitude angles with respect to the range coordinate system.

Attitude measurements determine the orientation of the missile at a predetermined sampling rate. The orientation measures are classified according to their relationship to the line-of-flight axis of the missile. Roll or spin describes rotation about this axis, while pitch and yaw describe the vertical and horizontal components of transverse oscillations of the missile about its center of gravity.

In the design and subsequent redesign of a test missile it is necessary to know the aeroballistic characteristics of the missile; attitude in flight is the chief of these characteristics and is an important piece of information on the flight of a missile.

In the past the Mitchell Chronographs were mounted on heavy-duty tripods and hand tracked with the aid of an auxiliary optical system. Lenses of 17- to 20-in. focal lengths were used with these cameras. As emphasis on attitude measurements increased, and the desire for more accurate data developed, longer focal-length lenses became a necessity. However, the longer lenses required more accurate tracking, and soon it was realized that a mechanical means was needed to track fast-moving objects.

As a result of tests conducted at NOTS, an Army model M-45 50-caliber machine-gun mount was acquired and used as the tracking mechanism. After some alterations and additions (such as removing the machine guns and installing cameras and lenses) the M-45 Tracking Camera Mount, popularly known as the "Gooney Bird," emerged.

Early versions of the "Gooney Bird" were mounted on an M-20 trailer. Power was received from batteries on the mount

Fig. 2. Cameraman operating M-45 Tracking Camera Mount (*Official Photograph,* U.S. Navy).

and separate generators powered the cameras.

The latest version of the M-45 is shock- and spring-mounted on an M-1 Tandem Trailer with stabilizing jacks and leveling provisions. A refractor of 48-in. focal length is mounted on one side of the operator and a half-scale version of this same lens is mounted on the other side. Pictures for attitude purposes are recorded by means of a 35mm Mitchell Chronograph Camera. A 16mm Mitchell Pictorial Camera may be used for documentary movies or a Fastax camera for super slow-motion studies. Each "Gooney Bird" is powered by its own generator system, which is mounted on a $2\frac{1}{2}$-ton 6×6 truck used as the prime mover for the M-45, and is thus a complete, independent unit capable of negotiating heavy sand encountered in the Mojave Desert (Fig. 1).

Performance and Operational Characteristics

The elimination of footwork around a tripod and the ease and speed of control of the M-45 have resulted in an appreci-

able gain in missile-tracking rate. Performance of the M-45 is very satisfactory when it is in good condition. In field use it is difficult to maintain optimum performance over sufficiently long periods. Tracking rates of 60 deg/sec are attainable in order to have a margin of safety beyond the experienced maximum rates of approximately 40 deg/sec. In tracking it is important that the tracking rate be similar to the speed of the missile to prevent blurred images which are difficult to measure. Acceleration characteristics are generally satisfactory, although some decrease in acceleration in elevation has been observed after some use. It is easier to track a fast-moving object in elevation only, without the azimuth component.

Chatter in elevation causing double images and the loss of tracking performance, both due to the old large-diameter ball bearings, have been eliminated by installing new tapered roller trunnion bearings. The present azimuth roller bearing is satisfactory and capable of smooth operation when clean, but it is poorly sealed and maintenance requires the disassembly of the mount.

The turret structure contains all of the rotatable supporting elements of the mount. The trunnions which carry the lens, camera and binoculars are mounted to elevate through an arc of $-10°$ to $+90°$ from the horizontal. The turntable, upon which the trunnions are mounted, rotates through 360°. The operator's seat, which does not move in elevation, is centralized in the mount structure and is tilted backwards about 45° to permit coverage of the full elevation range. The seat is adjustable so that the operator may regulate his position in order to follow the sight with minimum head movement (Fig. 2).

The mount movement and camera operation are controlled from a pair of control handles through a mechanical linkage mounted on a column which is straddled by the operator and within easy reach of his hands. The control handles may be moved in a vertical or horizontal arc or in a combination of both. The degree of movement and position of the handles control the speed and direction of the mount. Off-On switches, one mounted on each side of the control handles, actuate relays in the junction boxes which carry power to the cameras.

Camera Types and Uses

Instrumentation used on the M-45 is shown in Fig. 3. The 35mm high-speed Mitchell Chronograph Camera (Type B), which utilizes the 48-in. lens, is used to obtain the bulk of the required attitude data. This instrument combines the advantages of timing, large image, high speed and high tracking rate on the M-45.

The Mitchell Chronograph was designed with the cooperation of the U.S. Navy to meet special photographic requirements of the service. It is an intermittent-type, 35mm motion-picture camera. In order to insure the accuracy and precision required, the mechanism is manufactured to extremely close tolerances. The term "high-speed" is derived from the fact that the camera will operate at any speed up to 128 frames/sec using a 110-v a-c/d-c electric motor. A 12-v d-c motor is available for lower speeds.

A chronograph head with a 1/100-sec stop watch attaches directly to the specially designed camera base and photographs the image of the chronometer onto a corner of the frame on the emulsion side of the film utilizing the camera shutter.

The 16mm Mitchell Pictorial Camera, which utilizes the 24-in. lens, is used for documentary purposes only. This camera is similar to the 35mm Mitchell Chronograph except that it is not equipped with provisions for timing, and uses 16mm film.

The 16mm Eastman High-Speed and 8mm or 16mm Wollensak Fastax cameras (24-in. lens) are used to study detailed motion, separation of booster from the missile, time to action, and launching of

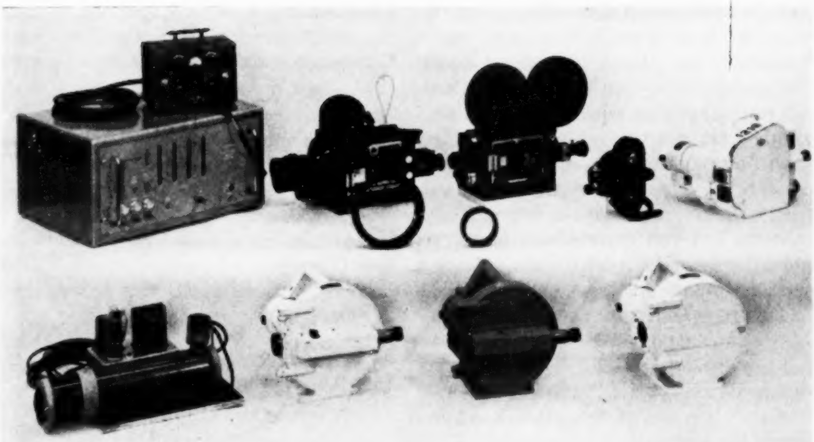

Fig. 3. Instrumentation used on M-45. Left to right, top row: Berkeley Time Interval Meter, 35mm Mitchell Chronograph with 48-in. lens in front, 16mm Mitchell Pictorial with 24-in. lens in front, 16mm Bell & Howell, 16mm Eastman High-Speed; bottom row: photoelectric Cell, 16mm Fastax, 8mm Fastax, 35mm Fastax (*Official Photograph,* U.S. Navy).

missile. These cameras are designed for high-speed photographic work with exposures ranging from 500 frames/sec to 3000 frames/sec in the EHS and up to 14,000 frames/sec in the 8mm Fastax.

Both of these cameras are of the continuous-film-drive type. A rotating optical flat is used to displace the image by an amount equal to the film movement during exposure. This system allows sufficient exposure, with reasonable definition, despite the fact that in some cases the film may be running through the camera at 200 fps. The effective operating time of these cameras ranges from approximately 0.75 sec to about 9 sec, depending on the frame speed.

Timing is provided by means of timing lamps built into these cameras receiving their pulses from a broadcast 1000-cycle pulse.

The 16mm Bell and Howell 70 TA Camera (Northrup modification) is used in place of the EHS and Fastax to study detailed motion, separation of booster from missile, and launching of missile. Normal operating speed is 200 frames/-sec which is sufficient for most high-speed work and eliminates problems connected with prism-type cameras. This camera gives higher resolution due to an intermittent-type motion, and a longer recording time due to a slower frame speed.

A photoelectric cell has been used in conjunction with the 24-in. lens to time an event from launching to burst.

Ansco color film is widely used on all attitude cameras to aid in distinguishing the image on film. The high-speed cameras have given acceptable results up to 500 frames/sec. Missiles have been painted with highly reflective and fluorescent colors to increase their contrast against the blue sky. The most successful colors have been Fire Orange, which also aids immeasurably in visual tracking, and Saturn Yellow.

Lenses

The increased emphasis on attitude measurements pointed up the need for better lenses for the M-45 Tracking

Camera Mounts. At first a 40-in. Bausch & Lomb Telestigmat $f/8$ lens was tried. Because it was meant to cover a large film rather than the 35mm frame size the resolution was poor and hence not suitable for our use. Very long focal-length lenses have been used with some measure of success, but much of the more recent developmental work on attitude cameras has concentrated on lenses of more conservative focal lengths with exceptional image quality.

Two such lenses are now in use on all M-45 Tracking Cameras: the 48-inch $f/8$ Thompson refractor lens, especially designed to cover the 35mm frame, and a half-scale version of this same lens, designed to cover the 16mm frame. The lenses were designed by Kenneth B. Thompson of the Thompson Optical Laboratory, Pasadena, Calif., and manufactured by Aaron J. Otto of Pasadena.

Thompson utilized air-spacing in the elements of the doublet as another degree of freedom for greater correction. This also does away with objectionable cemented surfaces which must be reconditioned often. The lens is scaled to guard against the entry of dust and is mounted in a cell which can be easily secured to the lens tube by four screws.

The front element glass is made of Borosilicate Crown-2 with an index of refraction $n_D = 1.51700$, the rear surface glass of Dense Flint-4, $n_D = 1.64900$. The effective focal length is 48 in. $\pm$ 0.25 in., the back focus is 0.989 times the focal length, and the diameter is 6.000 in., making the stop constant at $f/8$.

The elements are made from striae-free glass and the polished surfaces are coated for anti-reflection. Under the Foucault (autocollimated) knife-edge test, the lens shows uniform shadow with no evidence of axial astigmatism. The lens is corrected for longitudinal chromatic aberration for infinity focus. There is no turned-down edge figure and the test glass patterns were symmetrical to one-quarter fringe. Kenneth B. Thompson wrote that the design had exceeded his fondest expectations and compared the lens with the Rayleigh-Conrady tolerances as follows:

Aberrations	*Rayleigh-Conrady Tolerances*	*Residual Aberrations*
Marginal Spherical ($4\lambda/\sin^2\alpha'$)	0.02367 in.	0.00164 in.
Zonal Spherical ($6\lambda/\sin^2\alpha'$)	0.033 in.	0.0011 in.
Saggital Coma ($\lambda/2 \sin \alpha'$)	0.00018 in.	0.00009 in.

(λ is 0.000022 in. and $\sin \alpha'$ is $\frac{1}{2} \cdot f/$no.)

Performance tests made on the 24-in. lens show by visual observation that it is capable of resolving about 200 lines/mm on the optical axis and 100 lines/mm at the extreme edge of the field of a 16mm frame. The superb performance of the 48-in. lens has been aptly demonstrated by the resolving on film of tree branches at a distance of 15 miles.

The lens, as has been stated above, is mounted in a cell which can be easily secured to the lens tube by four screws. The lens tube has a metal shield protecting it from the sun, and after the lens is in place a lens shield $1\frac{1}{2}$ ft long further protects the lens. The camera, rather than the lens, is focused by means of a smooth-riding platform suspended by ball bushings and actuated by a rack and pinion. This method of focusing, developed at NOTS, permits optimum focus of the lens with comparative ease.

Orientation

The accuracy of pitch, yaw and roll measurements depends to a large extent on the levelness of the M-45. At low elevation angles the effect of a level error may introduce an error in yaw measurements of twenty times the level error itself. By orienting the M-45 immediately before or after an event it is possible in assessing the data to adjust the error.

At several permanent stations where

the M-45's generally are located are three red-and-white striped telephone poles placed 90° apart at a radius of about 1 mile. At the top and bottom of each pole targets are located very accurately to indicate perpendicularity. The operator takes short bursts of film on each pole.

To determine the out-of-levelness of the M-45 the film is assessed by placing cross-hairs on the targets and along the edge of the film and the angle determined. The correction to be applied to the assessed data can be computed from these measurements.

Timing

Timing for the 35mm Mitchell Chronograph is accomplished by photographing the projected image of a 1/100-sec 3-sec sweep stop watch or a 1/100-sec single-sec sweep electric clock onto a corner of the frame on the emulsion side of the film utilizing the camera shutter. Zero time of missile firing is indicated by a flashbulb at the launcher. The 16mm Mitchell Pictorial has no provision for timing. In the future the 35mm Mitchell will record time by means of a binary counter in place of the stop watch or electric clock.

The Fastax and Eastman high-speed cameras record timing by means of broadcasted pulses. The APR-13 transmitter, a modified version of a "tail warning type of radar," is used for putting the timing marks on the edge of the rapidly moving film. The frequency of the transmitter is 400 mc. As now used it is a pulse-modulated transmitter using 1000-cycle and 200-cycle synchronized pulses. At the receiver, which is a modified APS-13 receiver, the pulses light neon bulbs. The antenna for the receiver is a folded dipole.

Zero time of missile firing is indicated on the edge of the film by the start of the 1000-cycle pulses, the 200-cycle pulses being on continuously. Also, the 200-cycle pulse is of longer duration, thus making a larger mark on the film edge.

The range of the transmitter is approximately 5 miles and at the present time is being increased to about 10 miles with a new NOTS design of transmitter.

In the case where the M-45 is too far from the broadcasted pulses, a 1000-cycle "pulse generator" (NOTS designed and constructed) is used. Zero time from the pulse generator is indicated by the start of the 4-cycle pulse used by Askanias and other instrumentation. The 1000-cycle pulses from this generator are not synchronous with the broadcasted 1000-cycle pulses at Fire Control.

In the Fastax and EHS cameras an NE51 neon bulb is used. The pulse amplitude to the neon is approximately 180 v. No resistor is used in the circuit due to the high brillance of the neon necessary to show on the high-speed film. A special holder designed at NOTS is used to place the neon bulb in close proximity to the film.

At the present time no provision has been made for timing on the Bell & Howell 70 TA Camera.

In the case where a missile detonates in the air or around a target, a photoelectric cell will record the change in light intensity on an oscillographic record which was started when the missile was launched and recorded the 1000-cycle pulses, thus timing an event quite accurately.

Communications

The communication equipment for the M-45's consists of two identical sets of the Navy Type TCS-12 transmitter and receiver. One set is located on the M-45 itself and operates from the batteries through a 12-v d-c dynamotor power supply. This enables the operator to listen to a count-down over earphones or small speaker located close to his ear and to report coverage while seated in the mount. The other set, located within the trailer, is equipped with a large speaker and operates from a TCS-AC 110-v power supply. It is a stand-by radio to conserve batteries and is used to carry

necessary traffic such as warnings and progress of preparation previous to an actual event.

This equipment is primarily used on MHF in general ground range communications between the master control station, mobile units, and M-45 operators.

A VHF BC 639 receiver with an a-c power supply is also used for the monitoring of aircraft frequencies when aircraft tests are being conducted.

Power Requirements

The $2\frac{1}{2}$-ton General Purpose 6×6 International Truck is used as the prime mover for the M-45 Tracking Camera Mount. A 20-kw, 3-phase, 208-v, a-c diesel generator is mounted on the rear of the truck and supplies the power for the mount, cameras and communications. Each "Gooney Bird" is thus a complete, independent unit capable of negotiating heavy sand and able to move into any position desired.

The power drive on the mount consists of a Maxson variable-speed drive with a 12-v d-c electric motor. On several mounts, two 6-v batteries furnish the power to drive the turret structure and to power the communications on the mount. On one mount a 12-v d-c rectifier system has been added in place of the batteries and operates from the generator. Already placed into production are plans for operating the mount by a 3-phase, 208-v a-c motor and providing all M-45's with a slip-ring assembly to operate all equipment on the turret structure.

The power requirements for the M-45 hence include 3-phase, 208-v a-c for the mount to permit tracking in azimuth and elevation, 110-v a-c for the Mitchells, EHS, communications and timing, and 250-v d-c for the Fastax.

Conclusion

Attitude has taken an important role in the evaluation of the flight of a missile ever since the first caveman fashioned his spear and hurled it at his enemy. Scientists need an accurate method to determine the aeroballistic characteristics of a missile to develop it to the highest possible standards of perfection. The M-45 Tracking Camera Mount, though only an interim measure, has proven its worth in obtaining data that would have been impossible using hand tracking methods and inadequate lenses.

Though improvements are continually being made on the "Gooney Bird," it is not to be construed that it is the best or final solution to the problems encountered in the science of rocket photography.

Fundamental Problems of Subscription Television: the Logical Organization of the Telemeter System

By LOUIS N. RIDENOUR and GEORGE W. BROWN

The general problem of encoding a picture for transmission and decoding it at the receiver is considered, with special reference to the privacy problem of subscription, or pay-as-you-see television. Alternative ways of indicating the price of the program and acknowledging its payment are described. The factors which have led to the choice of system elements made in the Telemeter system become clear on the basis of this general discussion.

Subscription television is the name that has been given to a system for broadcasting television programs in such a way that a person desiring to view the program being transmitted must pay for the privilege, precisely as he would pay admission to a theater, stadium or other place of entertainment where such a program might be offered. This is not the place to debate the wisdom or desirability of subscription television, although it may be worth noting that the entertainment world is faced with a difficult financial problem posed by the broad public acceptance of television entertainment. Advertising sponsors of television programs cannot pay the producer of entertainment a sum consistent with what he has been accustomed to obtain by offering his entertainment in return for the payment of an admission fee by each individual patron. Total costs of television programs amount to sums less than five cents per viewer of the program; yet the total budgets represented by this modest cost per head are growing so large that most advertising sponsors are meeting them only with some difficulty.

A scheme which enables each viewer of a television program to pay a relatively modest "admission" fee would make possible much higher budgets for such special programs, with a consequent improvement in the quality of program material. It is largely for this reason that the proponents of subscription television systems are striving to develop effective schemes for making "pay-as-you-see" television practicable.

The Problem of Secrecy

Perhaps the most fundamental problem in subscription television is that of providing suitable means for rendering a *broadcast* television program *private*. The very contradiction in terms of the last

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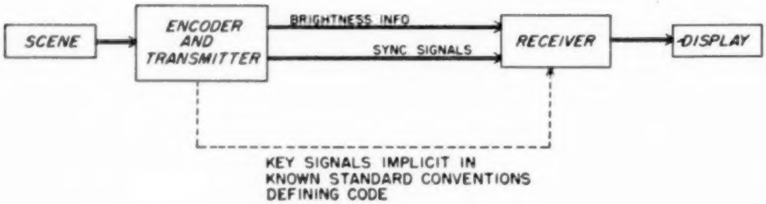


Fig. 1. Conventional television.

phrase illustrates the difficulty of doing this.

To begin with, we notice that the transmission of any intelligence, including the visual and aural signals involved in television, requires a coding of that intelligence into a form that is suitable for transmission (Fig. 1). The receiving apparatus then decodes the received signal and reconstructs from it the intelligence which was encoded at the transmitter. In the case of television, the coding scheme which has been adopted in this country is only one of a large number of possible coding schemes, any one of which might reasonably have been standardized. Indeed, in Europe and parts of South America different coding schemes have in fact been chosen. The successful reproduction of broadcast television programs depends upon the standardization, in transmitters and in receivers, of agreed coding conventions that will be adhered to.

Some of the conventions which are in current use are as follows:

(1) Elements of the scene to be transmitted are scanned in two interlaced fields per frame of 525 lines; 30 frames are scanned per second.

(2) The brightness of a picture element is represented in analog fashion by the amplitude of a quasi-single-sideband carrier on a scale from 0 to 75% of full carrier power; white is represented by zero, black by 75%.

(3) Synchronizing pulses of standard form, duration and location with respect to the video information are transmitted in the range from 75 to 100% of visual carrier power.

These conventions and others which govern the transmission of aural information are, of course, well known. They are mentioned here only to point out some ways in which nonstandard coding of television transmissions can be used to render a transmission "private" in the sense that acceptable reproduction of the visual and aural intelligence being transmitted cannot be accomplished by a standard receiver whose design is based upon the standard conventions.

A point of some importance arises here. Once the conventions for standard coding of television transmissions have been settled, it is then the goal of the receiver designer to build a receiver which will give adequate reproduction of picture and sound when these conventions are used and, in effect, will have nothing to spare. Competition in terms of price is so important that the well-designed receiver will have very little capability outside of the conventions of transmission and reception for which it has been designed. This means that, when we depart from those conventions in order to transmit a subscription television program, the nature of our departure from the accepted standards of transmission and reception will determine the amount and complexity of the auxiliary equipment required at the receiver to enable it to reproduce good pictures and sound under the novel conditions. Quality of program reproduction is, if anything, more important in subscription

television than it is in ordinary television. The subscriber, having paid for the program, will expect to receive picture and sound of good technical quality.

The agreed coding conventions for television immediately suggest a variety of ways in which the coding scheme can be changed. The standard line scan can be replaced by a different scanning raster; this may consist of an altered number of lines per field, of fields per frame, or both. It may involve bizarre sorts of scan such as spirals, to-and-fro zigzags, or other patterns; or perhaps an alteration in the order in which lines are scanned in a given field. The representation of brightness can be modified in various ways. The simplest is perhaps an inversion of the analog brightness scale, so that the picture transmitted is related to a standard transmission as a photographic negative is related to a positive. Alternatively, various digital schemes for indicating the brightness of a picture element can be imagined. The conventions regarding synchronizing signals admit of a rich variety of possible variations. The synchronizing signals can be suppressed or changed in form, or a change in the time relationship between the synchronizing signals and the scanning actions which they are to produce can be introduced. There are many other possible schemes for altering the convention under which television signals are encoded, and there is no point in discussing them exhaustively here.

Note that while we have talked only in terms of encoding and decoding the visual information, similar considerations apply to the encoding and decoding of the aural transmissions which accompany the picture signals.

Rather than discussing the relative merits of various specific nonstandard forms of coding, it will be useful to complete this discussion of the secrecy problem by dealing briefly with the manner in which the security of any private television transmission can be maintained inviolate. It is clear at the outset that no single choice of a nonstandard code, however elaborate may be the differences between it and the standard transmission convention, will insure the privacy that is desired. The persistent use of a single code will provide time for analysis of the coding method and the consequent construction and use of unauthorized decoders.

Neither can it be assumed that permanent privacy for coded transmissions can inhere in the constructional details of the decoder mechanism itself. It must

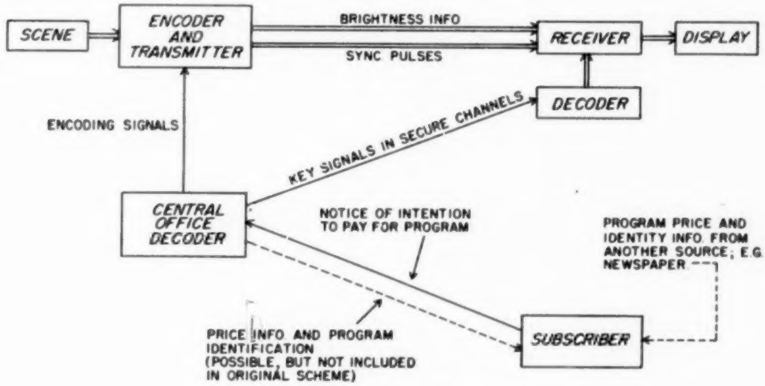


Fig. 2. The original Phonevision proposal.

be supposed that any decoding attachment which can be manufactured cheaply and in large numbers can also be readily duplicated by unauthorized people.

There remain two ways in which the privacy of the coded transmissions can be maintained. The first is represented, for example, by the so-called Phonevision system of subscription television (Fig. 2). A private channel for electrical communications between each subscriber and a central office is postulated in this scheme; because the cost of installing a special channel especially for subscription television would be entirely prohibitive, the use of telephone lines was originally proposed. The private communication channel is used for the transmission of signals which control the action of the decoder, upon indication by the subscriber concerned that he wishes to purchase the subscription program being broadcast. Without these signals, even a decoder of the sort used in the Phonevision system will not successfully decode the coded transmission. It is characteristic of this scheme, which we might refer to as a "closed system," that the necessary secrecy for the decoding process is provided by the existence of a private communications channel between the subscriber and the encoding center which controls the nature of the transmission.

Such a closed system is straightforward and has much to recommend it. In particular, the decoding attachment which must be added to the subscriber's receiver is likely to be simpler in the case of the closed system than it is in the case of the open type of system which we shall discuss in a moment. Unfortunately, the closed system suffers from the profound difficulty that the private channels of communication which it requires represent a vast capital investment on the part of some utility system. Any realistic assessment of the charges which should be made for the use of such channels to provide subscription television yields the result that such a closed system is very expensive to operate. There are other practical difficulties, such as the demand this system would make on the central-office switching facilities of the telephone system, but this is not the place to consider them.

Another form of closed system has been proposed under the name "Subscriber-Vision" (Fig. 3). In this system the subscriber himself cooperates in providing the secure channel for decoding information. This is accomplished through the physical transport of a code card or other

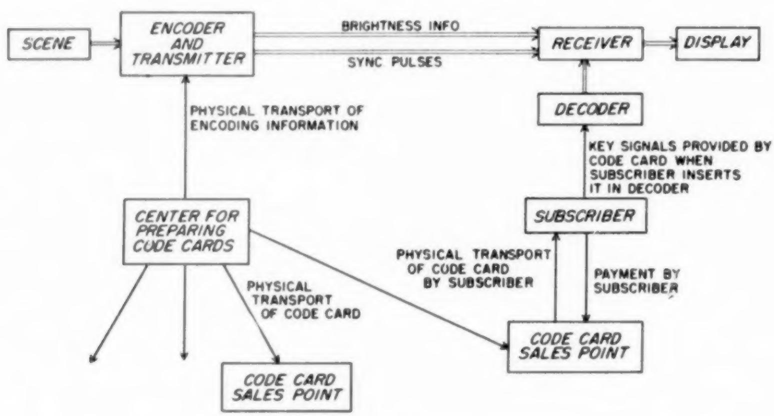


Fig. 3. The original Skiatron proposal.

physical code device; such code cards would be prepared with the necessary information to decode certain future transmissions, and then distributed to various points of sale in the communities where subscription television programs on this scheme were to be offered. A subscriber wishing to purchase a series of programs would purchase the corresponding code card at a point of sale, take it physically to his television receiver, and insert it into the decoding unit attached to his receiver. The decoding unit will be actuated in the proper fashion only when it has been provided with the code card appropriate to the program being broadcast.

Provided that the distribution of code cards can be adequately controlled and counterfeiting eliminated, it is apparent that this also constitutes a closed system, in the sense that a secure communication channel between the encoding center and each subscriber's decoder is provided, this time by the physical transport of a code card from the encoding center to the point of sale and from the point of sale to the subscriber's decoding unit.

In contrast with the closed systems just described is the class of system which does not require a secure channel for the transmission to each subscriber's decoding unit of the decoding information appropriate to the coded transmission being broadcast. In an "open system," as we shall call the latter type, the information necessary to decode the transmission is broadcast with the program. The fact that the transformation necessary to interpret this broadcast decoding information may be altered occasionally does not affect the fundamental difference between a closed and an open system: in the closed system, part of the decoding information is transmitted in a private channel; while in the open system, the decoding information is broadcast with the program.

The secrecy obtained in an open system clearly resides in the provision of a variety of possible codes which is sufficiently rich so that random experimentation with a decoding mechanism identical with that provided to authorized subscribers will still be unlikely to produce an adjustment which corresponds to satisfactory decoding. That is, the open system must rely upon cryptographic security; the closed system, having a private channel, can transmit its decoding messages "in the clear."

As is usual in cryptography, the method of encoding and decoding must not be allowed to remain unchanged for any considerable length of time, since this would provide opportunity for analysis of the code used. A complex sequence of encoding and decoding methods should be used; one of the functions of the decoder can be to provide for the programming of the appropriate sequence. At longer periods, the nature of the programming can be changed by altering settings in the decoder. To continue the analogy with cryptographic communication, we see that this corresponds to a change in the "key" information used to encode and decode messages, and requires a secure means of distributing the key information.

Given adequate cryptographic security, there is little doubt that an open system is preferable to a closed one. It does not involve the vast code-card preparation and distribution problem characteristic of the Subscriber-Vision system, nor does it require of the subscriber that he make an expedition to the store in order to be able to see a show. It avoids adding to the already serious problems of subscription television the further problems inherent in the use of a complicated and expensive wire communications system, as entailed in the original Phonevision proposal.

Accepting this conclusion, let us now discuss some of the ways in which an open system can be realized. We must first settle on the operating characteristics of a satisfactory subscription television system.

Operating Requirements for Subscription Television

The choice of the most desirable operating characteristics for a system of subscription television can be debated, and has been. No attempt will be made here to justify the choices which are characteristic of the Telemeter system, beyond remarking that they are based primarily on two main considerations: (a) convenience to the user of the system, and (b) maintaining as close as possible an analogy with practices which are standard and successful in existing forms of entertainment merchandising. Surely there can be no quarrel with the first consideration; the second has been adopted because of our belief that practices empirically arrived at through centuries of experimentation are likely to be sound. On these bases, then, we believe that the ideal subscription television system will have the following properties:

(1) *It must operate for cash.* With minor and trivial exception, entertainment has never been successfully sold on credit. There is no reason to suppose that the introduction of television as a medium for merchandising entertainment will change things radically enough to overturn the empirically justified view that it cannot be. It is our belief that the only practical way in which cash operation of a subscription television system can be achieved is through the medium of a coin-actuated mechanism.

(2) *Prices for individual programs must be capable of being varied.* Since the production costs of different programs are different, and the value to the viewer even of the same program may be different at different times (e.g., first-run, second-run and third-run motion pictures), a subscription system which operates on a fixed-price basis has surrendered much of its potential flexibility and usefulness.

(3) *Shows must be sold on a program basis, not on a time basis.* A baseball game that goes twelve innings must still be shown in its entirety to a viewer who has paid admission; a person who pays for a motion picture being shown twice in an evening must be permitted to sit through two complete showings of the picture for one admission, if he so desires, just as he could in a theater.

(4) *The identity, price and current status of a subscription television program should be announced for the benefit of those tuning to the channel carrying it, at all times during the program.* In the present Telemeter system, this is accomplished by means of an additional aural channel called the "barker," which is received when a subscriber tunes to a channel carrying a pay show. If the subscriber elects to purchase the show, the barker is replaced by the program sound as soon as the price of the show has been met. In the absence of some such provision, dependence must be placed on other means of informing subscribers as to the shows being offered. While much can be done through newspaper advertising, special weekly or monthly program circulars, spot announcements on radio and television, etc., we are of the opinion that the barker is a very important feature of a proper subscription television system.

(5) *An accurate record must be kept of every show purchased by every subscriber.* While the primary requirement for making such a record lies in the fact that the producer of entertainment is accustomed to being paid on the basis of a percentage of the gross admissions, there are ancillary reasons which make it desirable to keep a complete and detailed record, as we shall see.

We now consider the alternative logical organization of systems that meet these requirements.

Logical Organization of Subscription Systems

The elements of the most general subscription television system meeting the requirements specified in the last section are shown in Fig. 4, together with the information-flow among the various units. The transmitter must be con-

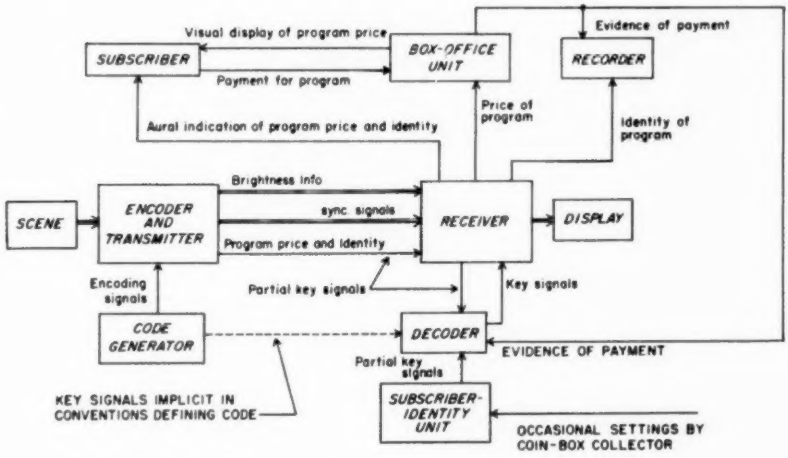


Fig. 4. Elements of the general coin-operated system.

trolled by a code generator which both governs the convention used in encoding and also supplies for transmission key signals that relate to the encoding method in use. The price and identity of the program must also be transmitted, usually in two ways. The "barker" gives to the subscriber an aural indication of price and program identity; at the same time, a suitably coded version of the program price must be transmitted to what we have called the "boxoffice unit." It is the function of this unit to display the program price, to receive the coins deposited in it by a subscriber who wishes to purchase the program, and, upon receipt of the full program price, to present evidence of payment to the decoder, which thereupon commences to decode the program, and to the recorder, which thereupon makes a record of the identity of the program purchased. Coded program-identity signals must also be transmitted, in order to enable the recorder to work.

It will be apparent that the decoder receives information from several sources. We have already noted that it is put into action by an evidence-of-payment signal from the boxoffice unit; this signal may or may not play a part in the actual decoding process, as we shall see presently. In addition, the decoder receives the key signals which the transmitter is sending to accompany the program, it has implicit in its construction some set of conventions defining a class of possible encoding methods, and it may receive from what is called the "subscriber-identity unit" further key signals that play a role in the decoding process. The function of the subscriber-identity unit will become evident as the discussion proceeds.

The fundamental organization of any subscription television system meeting the requirements we have laid down is that shown in Fig. 4. Detailed variation in the system design arises depending on the manner in which the four units of the subscriber's attachment — boxoffice unit, recorder, decoder and subscriber-identity unit — are associated with one another.

For example, consider Fig. 5. Here, by calling upon the subscriber himself to assist in the transport of decoding information, we have reduced to a minimum the amount of apparatus which must be

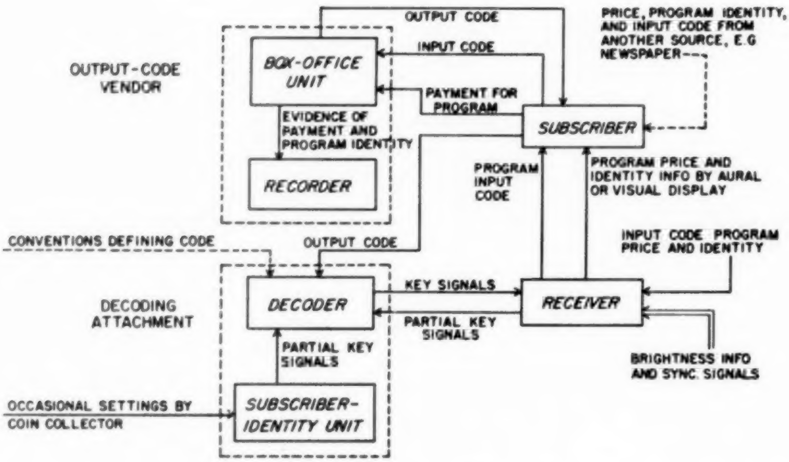


Fig. 5. Coin-operated system with subscriber intervention; remote vendor.

electrically connected to the subscriber's receiver. The boxoffice unit and the recorder have been associated in a device called a "vendor," which can be physically isolated from the "decoding attachment"; indeed, a single vendor can, if desired, serve a number of subscribers. Only the decoder itself and the subscriber-identity unit are associated in the individual decoding attachment.

The system shown in Fig. 5 operates as follows: The subscriber is informed (e.g., by the barker) of the nature and price of the program available on the channel to which he is tuned, and he is given in addition a code message which characterizes the program. This code message must contain an indication of the price and identity of the program, in order for the vendor to work satisfactorily. The subscriber then goes to the vendor and enters the code group characterizing the program, and another code group which serves to identify the subscriber himself. On the basis of these items of information, which together comprise the "input code" of Fig. 5, the vendor prepares itself to receive payment for the program. Upon the subscriber's meeting the price asked for the program, the vendor makes a recording of the identity of the program purchased and the subscriber's identity; it then presents to the subscriber a new code group (the "output code") which may simply be a message or alternatively may take some physical form, such as that of a code card.

The subscriber now returns to his set and enters the output code into its decoding attachment. On the basis of this information and that supplied it by the subscriber-identity unit, the decoder is actuated and the program is decoded. We now see one reason for the subscriber-identity unit. Without it, the full code required by the decoder would be available to the subscriber, and this code would be the same for all subscribers. Collusion among subscribers would then enable a single output code purchased by one subscriber to be used by the entire group, without any record being made of this fact, since the recorder is located in the vendor. It is therefore necessary to render each output code unique to each subscriber, which can be done by causing the input code, and therefore the output

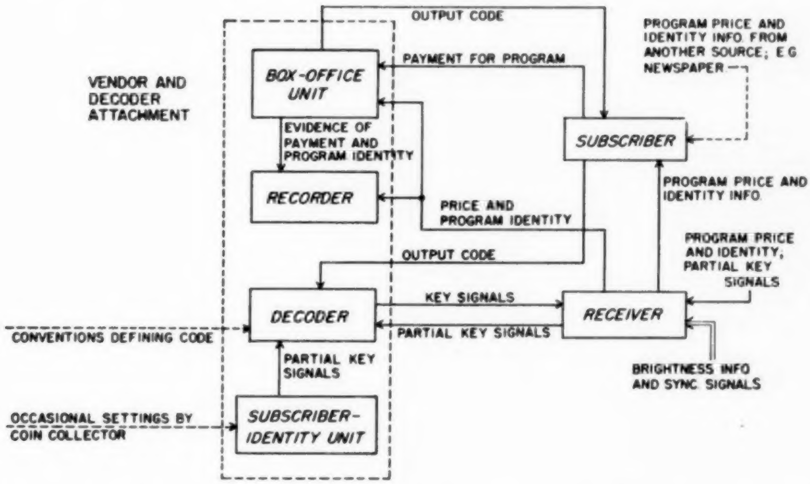


Fig. 6. Coin-operated system with subscriber intervention; automatic input code.

code, to be unique to each subscriber. The various individual output codes are then all translated back into the proper decoding pattern through the intervention of the subscriber-identity unit, whose settings have been chosen to match the variations in output code produced by the subscriber-identity part of the input code.

The system of Fig. 5 represents the maximum degree of subscriber intervention in the decoding process which we think is at all feasible. Figure 6 shows a system which is more nearly automatic.

In Fig. 6, the boxoffice unit and the recorder, which together comprise the remote vendor of Fig. 5, are associated with the decoder and the subscriber-identity unit in the subscriber's attachment, which must be physically and electrically joined to the television receiver. The information on program price and identity reaches the attachment directly from the television receiver, without the intervention of the subscriber. The output code is presented to the subscriber, who enters it into the decoder. As in the system of Fig. 5, and for the same reasons, a subscriber-identity unit is necessary to handle output codes which are unique to each subscriber. The part of the input code which represents the subscriber's identity can be set into the recorder and boxoffice unit in a semipermanent fashion, since the entire attachment is and remains in the possession of a single subscriber.

Another possible system is shown in Fig. 7. Here the subscriber intervenes to enter the input code, which has reached him via the receiver, perhaps through the agency of the barker. As in Fig. 6, the subscriber-identity part of the input code is built into the attachment and need not be entered each time the equipment is used. The output code now goes directly from the boxoffice unit to the decoder, entirely within the attachment. Under this arrangement, there is no longer any necessity for a complicated output code, nor for one unique to each subscriber. Since the output code is entirely unavailable to the subscriber, it can consist simply of the closing of a relay which actuates the decoder. An optional subscriber-identity unit is shown, for reasons which will become clear in a moment.

Actually, when the attachment to a

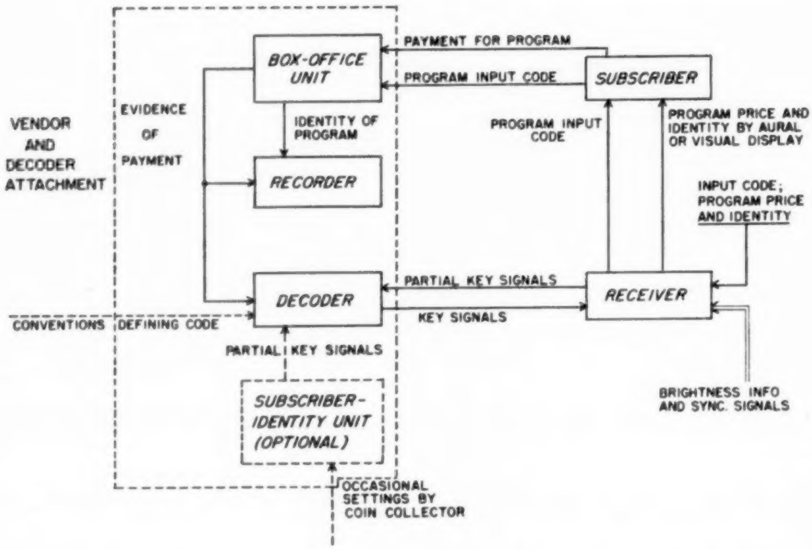


Fig. 7. Coin-operated unit with subscriber intervention; automatic output code.

subscriber's set includes the boxoffice unit and the recorder, as well as the decoder, both the input code and the output code may as well be made automatic. This produces some simplification in the equipment and also represents a system which makes the minimum demands upon its user. The resulting fully automatic coin-operated system is the one used by Telemeter. Its logical organization is shown in Fig. 8.

Price and program-identity information reach the Telemeter attachment directly from the television receiver; the price of the program is displayed visually to the subscriber by the box-office unit. Payment of the program price by the subscriber actuates the recorder and the decoder. An optional subscriber-identity unit is shown in connection with this system, as it was in connection with that of Fig. 7.

While the subscriber-identity unit is not needed in either of the last-mentioned systems to guard the integrity of the output code, since this code never appears outside the closed box housing the attachment, such a provision may be useful for the following reason. In any coin-operated system, a collector must periodically call to collect the coins that have been deposited in each home unit. The collector will occasionally find no one home when he calls, and will thus be unable to make a collection. One such failure to collect is tolerable, but two or more such failures lead to the danger that the coinbox will be overfull, or the recording medium used up, or both, before a successful collection is made. We may say parenthetically that this constitutes something of an argument in favor of the remote vendor, which can be placed where a collector can always have access to it. Nevertheless, the subscriber convenience afforded by the system of Fig. 8 seems to us sufficient to overwhelm this apparent advantage of the system shown in Fig. 5.

The difficulty just mentioned can be ameliorated by the use of a subscriber-identity unit, not to identify any par-

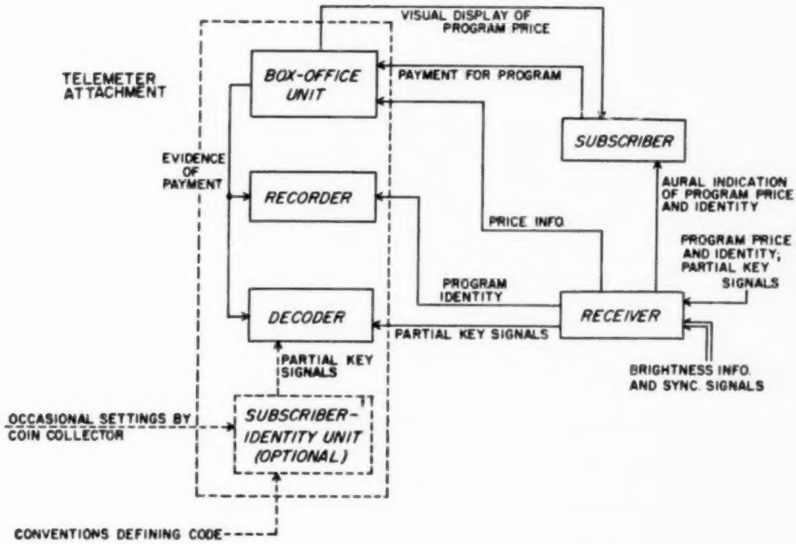


Fig. 8. Telemeter: a fully automatic coin-operated system

ticular subscriber, but rather to indicate that a sufficiently recent call by a collector has been made. That is, the subscriber-identity unit used in this fashion may be provided with a code sufficiently redundant so that its June setting by the collector will operate satisfactorily during June and July, but not August; the July setting will operate for July and August, but not September, and so on. This will permit one unsuccessful call by the coin collector, but no more than one; if a second unsuccessful call is made, soon thereafter the Telemeter attachment will no longer operate satisfactorily. Occasional settings of the subscriber-identity unit by the coin collector have been indicated in Figs. 4–8 inclusive, to provide for this use of the unit.

Realization of the Telemeter System

It will be apparent from the foregoing discussion that many alternative ways are available for realizing a system of the logical organization and operating features preferred by the International Telemeter Corp. A vigorous program of development is being carried out to determine the optimum detailed design for the system; since this is still in progress, it would be premature to discuss here the details of the encoding, decoding and other means used in the Telemeter system. The authors feel strongly that, as is usual in engineering development, a decision on what had best be done is far more important than the details of how it is to be accomplished; the present paper is therefore devoted to establishing a rational basis for the design of a satisfactory pay-as-you-see television system.

Discussion

Wm. H. Offenhauser, Jr. (Andre DeBrie of America, Inc.): I see that the author has used an entirely new set of terms with which this Society is totally unfamiliar. For instance, the terms encode, decode, and secure channel are basic terms that have not appeared previously in our proceedings. Will the author be good enough to add an explicit glossary and bibliography at the end of his paper that will enable readers of

our *Journal* to appreciate these new concepts and terms?

Mr. Ridenour: I'll do my best. "Secure" is a word that the Navy uses in a different sense from everybody else. As a matter of fact, the Navy uses it in two senses. One means "to sweep out" and the other means "to keep private"; it's the "to keep private" use of the word that I had in mind. "Encoding and decoding" is just a more precise way of talking about what is often called "scrambling and unscrambling." The latter terms are inappropriate, because, in order to get a picture through a needle's eye the way you must in television, you have to encode the picture in the first place and decode it at the receiver. Thus, all that is meant by "scrambling" is that you use a nonstandard method of coding and decoding. Note also that "nonstandard" is a term which has only a geographical reference; the transmission code that we regard as standard would be quite unintelligible to a French receiver. It is important to the understanding of the subject not to use the terms "scrambling and unscrambling" but to use "coding and decoding" instead.

Axel Jensen (Bell Telephone Laboratories, Murray Hill, N.J.): It is quite true that we are in a new field. New ideas are coming out all the time; and when the engineers have new ideas they put words to them — you can't help that. It's up to Societies like SMPTE and IRE later to take a hold of those things and try to standardize some of the terms that are being used. I don't think we should worry too much about it in the very early stages. Eventually those things will get themselves straight.

Anon: I would like to know who owns and maintains the auxiliary equipment for the receiver.

Mr. Ridenour: I'm talking out of turn to answer that question, because this is a matter of policy that will have to be decided after a considerable amount of thought. However, it seems likely that the attachments to people's receivers will have to be managed on the same basis as are telephone instruments. That is, they will have to be, and remain, the property of the operating company, for several reasons. One is that you have to be able to fix them; another is that you must have access to them in order to collect money if it's a coin-operated mechanism, and so on.

Anon: Then in view of that would you say that it is actually cheaper than a telephone line?

Mr. Ridenour: I have asked some telephone engineers about the capital cost represented by a single home telephone installation; it runs well over $350 in the operating company of which I inquired. Now I'm quite sure we can build a satisfactory pay-as-you-see unit for considerably less than that.

Closed-Circuit Video Recording for a Fine Music Program

By W. A. PALMER

The requirement that an experimental series of "Standard Hour" television concerts be released in six markets on 16mm film posed special problems of economics and quality. Closed-circuit special video recording was used incorporating a number of unconventional techniques such as the use of direct-positive "reversal" masters and negative-image release prints. Prescoring was used for all musical numbers and audio procedure made use of $\frac{1}{4}$-in. magnetic tape, 16mm magnetic film, and a direct-positive electro-printed variable-density sound track for final release.

When the Standard Oil Company of California decided to make an experimental television version of "The Standard Hour" musical programs, there were several requirements immediately apparent.

(1) The program would have to be released in six western markets from 16mm film since a network hook-up for these stations was not available.

(2) Audio quality from the 16mm film would have to meet AM radio-network standards so that the radio audience, built up over a period of twenty-five years, would not feel a loss in musical value as a result of the addition of the visuals.

(3) Each program would include a symphony orchestra, a "star" vocalist, a new young "discovery," an instrumental soloist and a ballet number.

(4) Technical procedures followed would have to be efficient and flexible enough to produce the required film material within moderate budget limits.

(5) The caliber of the musical performance and the "stage-craft" used on settings would have to be of the highest order.

After a number of tests and the making of a pilot film, it was decided to use closed-circuit video recording in conjunction with prerecording of the music. In other words, there was to be a combination of television and motion-picture techniques to take advantage of the efficiency of the electronic cameras and still have the advantage of the more flexible handling of musical numbers which has been common in the theatrical motion-picture industry for many years.

Presented on April 28, 1953, at the Society's Convention at Los Angeles by W. A. Palmer, W. A. Palmer Films, Inc., 611 Howard St., San Francisco 5, Calif.
(This paper was received March 27, 1953.)

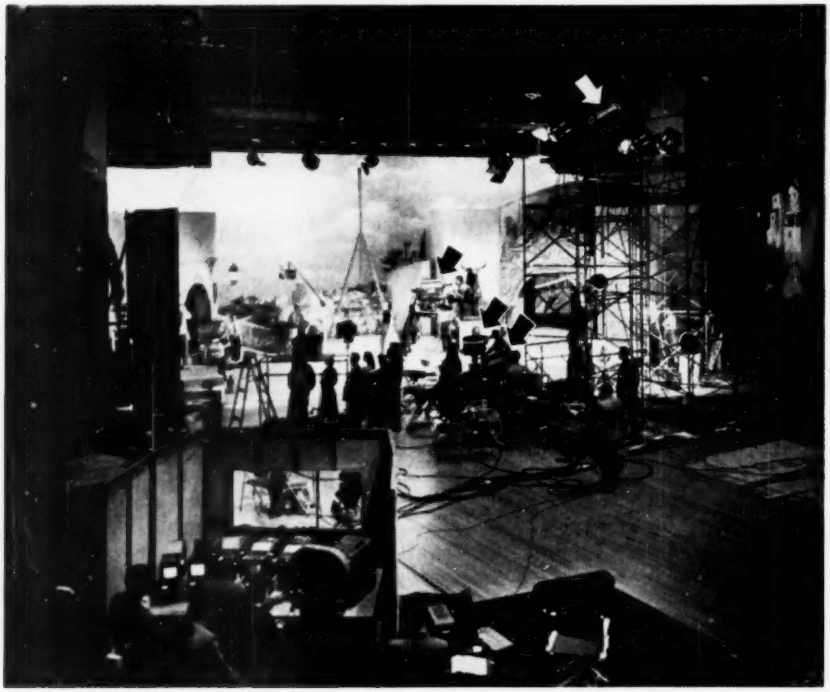


Fig. 1. General working area; television cameras indicated by arrows.

Or expressed in terminology which has been suggested before: "Electronic Motion Pictures" were to be used.

The programs were produced in "units," each unit supplying several musical numbers which could be spotted on several programs throughout the series. In this way it was possible to have several appearances of a given artist and achieve a great variety in each program. A "unit" involved four days shooting during which enough material for one and a half programs was obtained.

Audio

The production of "The Standard Hour" television programs started with the recording of the musical sound tracks on Ampex $\frac{1}{4}$-in. tape recorders at the ABC San Francisco studios. The $\frac{1}{4}$-in. tape is, of course, not a synchronous medium, but since "prescoring" was to be used, an absolutely synchronous method was not necessary at this stage and the unperforated tape made possible more precise editing.

Two Altec 21B microphones were used, one general pickup for the orchestra and one for the soloists.

In preparing the music, a great deal of advantage was taken of the facility of tape editing, permitting the combination of several takes to get a more nearly perfect performance. With nonperforated magnetic tape, the assembly of parts of a musical number could be accomplished with great precision, since a splice could be made at any desired point, such as between sixteenth notes, without evidence that a cut and splice had been made.

With the completion of the editing of

the tapes, the music was re-recorded to magnetic 16mm perforated film running at 72 fpm. This became the master sound track for all subsequent operations.

At the same time, an additional transfer of the music was made to a 16mm direct-positive photographic sound track while a voice called out numbers at intervals to identify various musical phrases. The photographic track, recorded at the standard 16mm speed of 36 fpm, was used to play back and cue the artists during photography.

Disks were also made and given to the artists so they could rehearse with the recording in privacy prior to the shooting sessions.

Equipment for Photography

During the photography sessions at the Civic Auditorium at Richmond, Calif., four standard RCA image-orthicon camera chains were used as in a regular KGO-ABC "remote" job.

Figure 1 shows the general working area with television cameras (indicated by arrows) on the set in the background and the control and recording equipment in the foreground.

A Houston-Fearless "Academy" crane was used for most shots where a mobile camera was needed. A second camera was mounted on a Fearless baby boom or perambulator and a third was mounted on a RCA pedestal. The fourth camera was mounted on a field tripod, usually located on a high parallel to cover "pattern" shots on ballet sequences.

The usual lens complements were available for all cameras with the addition of a Walker Electro-zoom lens.

All four cameras, with their associated field monitors, were fed through a field-switching unit to a TM5A monitor which had a video-recording camera focused on it.

The 16mm video-recording camera used is of special design with a shutter-optical system combination permitting a shutter-bar free picture to be obtained from the regular 10-in. P4 long-persistence phosphor kinescope.

An optical system in the camera shows an enlarged upright image of the film aperture. Line-up, focus and "picture splice" phasing is done by visual inspection through this optical system and the image on the film may be watched during actual photography.

Picture quality on the monitor was judged by eye with the aid of a Norwood-Bolex exposure meter to set the average light level. The hemisphere light shield was not used on the Norwood meter but the bare cell was held close to the tube face to make a reading.

Lighting equipment was conventional, mostly 2-kw juniors and 750-w "babies," with a few 5-kw seniors and skypans. The great sensitivity of the image orthicons permitted a light level considerably lower than required for regular motion-picture photography even though lenses were usually used at about $f/5.6$.

Photographic Procedure

In photographing the various musical numbers, the photographic sound track with its voiced cue numbers was played back through horns on the set while the artists sang or played along with the track. As an added help in synchronizing, "clicks" were placed in the track wherever there was a drastic change in tempo or a rubato. Audio playback equipment is shown at the extreme right of Fig. 2.

Sometimes, whole musical numbers or at least half of a number would be photographed in one "take," individual scenes being switched or electronically "cut" from the several cameras. At other times one camera position at a time was used and the "cutting" or editing left for the finishing operations in making up the final shows as is the usual technique in regular film making.

As the recording or photographic process was going on, the artists performing in synchrony with their played-back music, the sound track was also being re-

Fig. 2. Arrangement of monitors and controls; audio playback equipment at extreme right.

recorded on a "single system" modulator within the 16mm video-recording camera on the same film that recorded the picture. This track was used as a guide for matching the master sound track in the later operations and served as a sound source during the showing of "rushes" and in the "rough cut" stages of making up complete programs.

Du Pont Type 930 or Eastman Plus X film was used and processed by the reversal method to give a direct-positive master. The commentator and the program pages were also photographed on 16mm reversal film by conventional motion-picture methods.

Make-up of Complete Programs

Since the final release would have to be on 16mm film run on conventional iconoscope chains, experiments were made with different qualities of both positive and negative prints off the 16mm masters with a view to obtaining the best transfer characteristics or gray-scale rendering. The negatives were run on the television film chain with polarity reversal to yield a positive image. These test prints were also put out over the air as an engineering test and observed on home receivers. The most satisfactory transmission resulted from the use of the negative images since the well-known highlight compression characteristics of the iconoscope became compression of the shadows which was actually beneficial to gray-scale rendering. By virtue of the 16mm master reversal film, the negative television release prints could be contact-printed directly without incurring losses in successive steps. The 16mm reversal original thus became the master

from which all air release prints were made.

The original reversal film had a sound track recorded alongside the picture as described above and from this composite original, a work print was made by the reversal method to be used for editing. This was accomplished more easily than would have been the case if the usual "double film" technique were used. The usual objections to editing a composite sound-and-picture film did not apply here because the various scenes that were to be joined had an overlap of common sound track of identical modulation. It was therefore only necessary to find the duplicate modulations on two scenes to find the accurate cutting point by reference to either picture or sound track. The fact that the cutting point was 26 frames behind the sound modulation created a minor hazard that had to be kept in mind to avoid errors.

When the final assembly of the entire program was made, combining the various ingredients, stock opening and closing, audience reaction, commentator "on camera," program pages, and institutional message, it was necessary to go to separate films for sound track and picture. However, a shortcut was used to avoid having to run many of the previews in interlock with three sound tracks.

The voice track for the commentator was recorded on 16mm magnetic film at 36 fpm and this was assembled on the same reel interspersed with the photographic-cue track which was used for playback during photographic sessions.

Interlock projections of the entire program could then be made with just one sound track, the combination magnetic-voice and photographic-music track running in synchronism with the picture work print. A special reproducer for this combination sound track was devised so that both magnetic and photographic sound could be reproduced as each type alternately passed the reproducing point.

This combined photomagnetic reel also served as a guide to set up the master music tracks which were double length, that is 72 fpm for maximum fidelity, having a frequency range of 20 to 15,000 cycles. The matching between the combination photomagnetic track and the 72-fpm magnetic track required a synchronizer with a two-to-one gear ratio between sprockets.

Making Final Release Prints

The master 16mm reversal positives were set up in A and B reels for the entire length of the programs since there were many effects, particularly lap-dissolves, in each program. Wherever possible in the musical numbers, each master scene was left in its full length so that the placement of the dissolve could be changed if desired for improved effect after the first answer print or for a different editing in future use of the same material.

Eastman Type 7365 Fine Grain Duplicating Positive was selected for the negative-image release prints which were contact printed from the master positive A and B rolls. The stock had been first prefogged on the picture area only, to a density of 0.2. This served to flatten out the toe of the emulsion characteristic and still further improve shadow detail in the final television transmission.

The picture was printed to have a density range in the negative image from a maximum of 1.5, representing the highest highlight, to 0.2 for the deepest shadow. The film was developed in a D76 negative developer to a gamma of 1.0.

Electrical Printing of Sound Tracks

The sound track was re-recorded or electro-printed to each release print from three sound channels running in synchrony. One channel had the commentator's voice on magnetic 16mm film (the magnetic part of the combination photomagnetic film used in editing). A second channel had all the musical numbers and was the 72-fpm 16mm magnetic film.

The third channel was used for applause tracks.

Each applause track was an authentic complete recording taken from one of "The Standard Hour" radio broadcasts and started with the normal scattered claps, building up to the full volume and gradually subsiding.

The Type 7365 emulsion with its extremely fine grain and yellow dye is most suitable for a high-quality printed sound track but posed some problems in regard to an electrically printed transfer because of the extremely low sensitivity, the emulsion speed being approximately one-ninth the speed of Eastman Type 7302 stock.

Since a satisfactory balance density for a variable-area direct-positive track is very low[1] when applied to medium-contrast positive emulsions, it seemed desirable to use a variable-density track.

The sound track was transferred to the 7365 emulsion by a Western Electric RA1231-C recorder equipped with a special modulator. This was an adaption of the RA294 mirror-type modulator[2,3] with revised optical system designed to give a variable-intensity modulation and compensate for the emulsion characteristic of the 7365 stock yielding a linear-density record in the range between a density of 1.0 and the clear film base. The unusually large mirror of the modulator (6.7 × 10.0 mm) made possible adequate exposure of the film without overvolting the exposure lamp. Nine decibels of noise reduction was used since the optical compensation for the emulsion characteristic extended through the "toe" to well into the "straight-line" portion. This gave a sound track with a frequency response from 30 to 6000 cycles and with a signal-to-noise ratio of about 40 db, meeting the standards of AM network broadcasting.

Conclusion

The method of closed-circuit video recording described makes possible a very efficient means of good quality television transcription with all the flexibility of live-television camera technique combined with the editing and selection advantages of motion-picture production.

The use of prescoring for a musical program was shown to be entirely practical and eliminated all problems of microphone placement as well as insuring flawless musical performance.

The enthusiasm of the artists for the method was noteworthy. Most volunteered their preference for this combination of television and motion pictures wherein the intense pressure of live-television production and the boredom of painstaking motion-picture production are each tempered to a happy medium.

References

1. John G. Frayne, "Electrical Printing," *Jour. SMPTE, 55:* 590–604, Dec. 1950.
2. R. W. Benfer and G. T. Lorance, "A 200-mil variable-area modulator," *Jour. SMPE, 36:* 331–340, Apr. 1941.
3. W. R. Goehner, "A new mirror light-modulator," *Jour. SMPE, 36:* 488–496, May 1941.

Discussion

Ralph Lovell (NBC, Hollywood, Calif.): Bill, you were very modest about the camera. I think you just mentioned that it was specially constructed. Would you be kind enough to tell us a bit more about how you designed it and from what source you started building this camera?

Mr. Palmer: The camera is still under some development. It might properly be a subject for a future paper. The basic mechanism makes use of parts from a Bell & Howell projector shuttle with a shutter optical system which permits a fade-out fade-in type of action resulting in a "picture splice" which occupies about 30 television lines instead of the usual three or four. To describe it more fully, of course, would require some detail which time does not permit. The unusual feature is that it makes possible the use of a long-persistence white phosphor kinescope. The shutter action can be compensated for any given emulsion to give a shutter-bar free recording.

Mr. Lovell: You said a Bell & Howell movement. Does that indicate a Bell & Howell projector movement?

Mr. Palmer: Projector movement, yes.

Mr. Lovell: Did you also do the same thing with the 35mm movement, make a 35mm camera?

Mr. Palmer: I made a 35mm camera which was used only on the later recordings and because we did not have complete material in 35mm we used it as a protective. It has an accelerated Geneva projector movement with a shutter mechanism similar in principle to the 16mm camera.

Mr. Lovell: I think we all admire you for your ingenuity in making a camera out of a projector. I'd like to ask you, in view of your experience, if you were to initiate another series, what changes would you make? I'm particularly interested — would you continue with the P4 phosphor, or would you try to use the P11 as many other people do?

Mr. Palmer: We would, of course, like to have a high-definition system, since we don't have to be compatible with the 525-line system on a closed circuit. We would probably prefer to continue the use of the P4 phosphor because it allows us to judge the picture quality by eye, a very important factor. In this experimental series we could tell directly from the gray scale apparent on the monitor, the type of recording we would get. The emulsions and the processing chosen were such that we had approximately a unity gamma system through to the home receiver. Actually we did gain a little contrast, but our visual impression on the P4 phosphor gave us a good indication of the final result in the home. Our tests did not indicate that, within the limitations of the 525-line system, we would gain appreciable definition from a P11 tube.

Benjamin Berg (Benjamin Berg Agency, Los Angeles): What is the pulldown time on your shuttle?

Mr. Palmer: The camera shuttle operates with approximately a 30 degree pulldown. Seventy-two degrees are available for shutter action and pulldown so we had a little leeway of some 40 degrees to spread the picture splice.

Anon: I'd like to know how you accomplish this splice of the picture. Is this a conventional shutter or does the density of the shutter itself vary?

Mr. Palmer: It's a little hard to describe in a brief answer, but the shutter is a rotary type with two moving parts which cooperate with and are a part of the optical system. The shutter creates an intensity variation at the film, so that there's no area modulation of the image at the film aperture and the rate at which the shutter opens and closes is variable by adjustments that can be made, similar to the use of shaped masks for direct variable-density recording with a mirror-type modulator.

Engineering Activities

Stereophonic Sound

A major revolution is quietly taking place in the sound end of the motion-picture industry. Stereophonic sound has made its "debut," has been well accepted and is apparently here to stay, but its entry has been somewhat obscured by the simultaneous and very dramatic introduction of 3-D and wide screens.

All that glitters is not gold and all multiple-track sound recording is not stereophonic, although often highly touted as such. True stereo (auditory perspective of lateral location and depth) requires the use not only of multiple recording channels but properly spaced microphones as well. Pseudo-stereo may employ one mike in the studio whose output is later re-recorded on one or more of the multiple tracks to simulate a stereophonic effect. The resulting sound illusion on the screen may, however, if astutely done, bear a marked resemblance to the original sound scene and if it is, the audience will probably feel a sense of sound perspective.

Magnetic recording (the stereo sound medium) was first used in motion picture studios in 1947 and was confined to original recording from which a photographic track was re-recorded for release. The rapid adoption of the magnetic medium led early to a need for industry standards. The Society's Sound Committee took the initiative here and after much discussion and some delay a 35mm, 3-track, magnetic proposal was approved as an American Standard (PH22.86-1953 in the May 1953 *Journal*).

The development of this standard greatly furthered the use of stereo sound in the theater, for it provided a ready vehicle for both the studios and equipment manufacturers to rapidly exploit this advance in sound realism.

However, in one respect this may be characterized as "one step forward and two steps back" for, as they were in the first days of sound, picture and sound are again on separate media. The separate magnetic 3-track reproducers and selsyn sync control systems now used in stereo sound are certainly a far cry from the phonograph and disk record used in the twenties. Nonetheless, they are looked upon as an added complexity in the projection booth, and at that, but a stopgap measure. Just how soon composite picture and stereo sound will be generally available is anyone's guess at this point, but it certainly looms as an early eventuality. The August 13, 1953, demonstration of CinemaScope's composite picture and stereo sound undoubtedly lends weight to the notion that the single-film system is, at any rate, technically feasible right now.

This places the exhibitor in somewhat of a spot. Should he buy dual-film stereo sound equipment now or hold off until single-film features and equipment are available?

It would appear that the exhibitor would have to consider three factors before making his decision:

(1) the effect of 3-D sound on boxoffice receipts,

(2) the number of dual-film features scheduled for production and release, i.e., pay-off time,

(3) amount of first equipment which could be converted for use with final equipment.

Estimates on the latter two factors are available. John Hilliard, Chairman of the Sound Committee, conducted an informal survey of the Hollywood studios the first week of August which revealed that roughly 40 dual-film features are in production or in the planning stage. A recent conference of East Coast engineers and exhibitors estimated that about 75% of initial investment in stereo sound equipment (amplifiers, speakers, etc.) could be used directly in a later conversion to a single-film system.

Status of the Theater-Screen Survey

The survey initiated by the Theater Engineering Committee in May 1953 was

described in the preceding *Journal.* At this writing some eight thousand questionnaires have been distributed with but 250 returned. At least twice this number of returns are required before a statistical analysis can be made. Since this survey can be an important factor in standardizing a new aspect ratio, exhibitors are being urged to request, fill out and return these questionnaires.

Standards

The new is based on the old: despite its active participation in the new developments, the Society is continuing unabated its usual standards activity. To this end, the Board of Governors, at its July meeting, approved 11 reaffirmations and two revisions of existing standards:

Reaffirmations: PH22.27, -.37, -.46, -.47, -.60, -.62, -.65, -.66, -.67, -.69 and -.70.

Revisions: PH22.43 and -.44.

These standards have since been submitted to the Photographic Standards Board of the ASA and will in all likelihood be given formal ASA approval within the next two months.

In addition the following projects are in the works:

Film Projection Practice Committee: withdrawal or revision of American Standard PH22.28-1946, Projection Rooms and Lenses for Theater, SMPTE 628.

16mm and 8mm Motion Pictures Committee: withdrawal of American Standard PH22.54, 16mm Travel Ghost Test Film, SMPTE 611; and revision of two American Standards — PH22.15, 16mm Film Perforated One Edge — Usage in Camera, SMPTE 518, 614; and PH22.16, 16mm Film Perforated One Edge — Usage in Projector, SMPTE 519, 615.

Sound Committee: four proposed American Standards — SMPTE 617, 35mm 3-Track Magnetic Flutter Test Film; SMPTE 618, Azimuth Alignment Test Film for 35mm 3-Track Film With Magnetic Coating; PH22.88, Dimensions for Magnetic Coating on 8mm Motion Picture Film, SMPTE 624; and SMPTE 626, Magnetic Coating on 16mm Film Perforated Two Edges. And revision of three American Standards — PH22.42, 16mm Sound Focusing Test Film, SMPTE 622; PH22.45, 16mm 400 Cycle Signal Level Test Film, SMPTE 623; and PH22.57, 16mm Buzz Track Test Film, SMPTE 621.

Copies of any of the above proposals are available upon request.—*Henry Kogel,* Staff Engineer.

Southwest Subsection Meeting

A successful meeting of the Subsection was held on May 20 at the Beard & Stone Electric Company auditorium in Dallas. The membership of the North Texas section of COMPO were invited to meet with us to hear Herbert Barnett's speech to the Western Pennsylvania exhibitors convention. However, COMPO had a benefit barbecue for the Waco tornado victims the same evening so we had only two guests.

There were 18 people present including Hervey Gardenhire who has come about 300 miles from O'Donnell, Texas, for every meeting we have had except the one of last November when the roads were too "iced-up" for travel; also there were members from San Antonio and Austin.

Mr. Barnett's paper was read by program chairman I. L. Miller, and subsection chairman Bruce Howard read W. A. Palmer's Los Angeles convention paper, "Closed Circuit Video Recording for a Fine Music Program."

There was some discussion on the type of meetings held thus far by the Subsection, and a committee composed of Hugh Jamieson, Sr., J. Oakleigh Hill and A. B. Chapman was appointed to draft a letter to the Southwest Subsection membership, asking their preference as to program material, meeting places and choices of days of the week. It was hoped that information in response to this inquiry would be on hand in time to be of use in planning the first Fall meeting.—*Hugh Jamieson, Jr.,* Secretary-Treasurer, Southwest Subsection, 3825 Bryan St., Dallas 4, Texas.

Central Section Meetings

Following the May 21 meeting described in the June *Journal*, the Central Section soon held two more meetings on May 27 and June 11, making an unprecedented total of three meetings taking place in as many weeks. The May 27 meeting, held at the Western Society of Engineers, Chicago, drew about 220 for an evening of stereoscopy. Those attending saw what was described as the first industrial 3-D film to be made — *Packaging the Third Dimension*, by Academy Film Productions Inc., Chicago, dealing with the manufacture of corrugated cartons. Guests from the Northern Illinois College of Optometry were also on hand at this meeting to hear an interesting and provocative paper on "Beneficial Effects of Properly Produced, Projected and Viewed Stereoscopic Motion Pictures on Binocular Visual Performance," by R. A. Sherman, of Bausch & Lomb Optical Co., Rochester, N.Y. This paper had already attracted considerable attention at the Los Angeles Convention, where it was first presented. It was plain from the success of this meeting that 3-D is a prime attention-getter, and it is likely that additional papers on this subject will be presented in the Fall.

The meeting on June 11 was held at the Geo. W. Colburn Laboratory, Inc., Chicago. Mr. Colburn gave a report describing the progress that has been accomplished in applying the SMPTE proposed standard for printer light cuing of 16mm motion-picture films; and a paper by Edward Yuhl on the RYB "Wireless Mike," a lightweight transmitting microphone, was presented by Henry Ushijima. About 125 attended this meeting, which concluded with a tour of the Colburn Laboratory facilities, and refreshments.

Tentative meeting dates for the Fall Season have been set for September 11, at Dayton, Ohio, and October 15, November 12 and December 10, at Chicago.—*James L. Wassell*, Secretary-Treasurer, Central Section, 247 E. Ontario St., Chicago 11.

Pacific Coast Section Meetings

Under the direction of Herbert Farmer, Faculty Advisor and Acting Head of the Department, and Kenneth Miura, Chairman of the Student Section, SMPTE, the fifth meeting of the Pacific Coast Section of the SMPTE was held at the Department of Cinema, University of Southern California, on May 19, 1953.

Society members and guests had dinner on the campus, followed by a presentation of short papers and demonstrations of motion-picture productions and special projects presently under way at the campus.

The program opened with a recent short motion-picture production made by the Department of Cinema. Following this, Richard Polister spoke on "The Scope of Motion-Picture Production in Colleges and Universities," reviewing the technical progress of production units in various universities and colleges throughout the country. Nicholas Rose, Director of Research in the Department, then spoke on "Analysis of Audience Reactions and Behaviors." He described systematic techniques for studying audience behavior in the evaluation of film effectiveness, and explained their development in the Research Division of the Cinema Department. A film demonstration of the various processes used was shown. "Uses of Silhouette Special Effects" was the subject explored by William Mehring, Instructor in Cinema, and covered a new motion-picture technique which has become a worthwhile classroom tool in the study of directional problems. A review of the production activities of the Department was given by Wilbur T. Blume, Director of Productions, with accompanying screen excerpts from recent films. The formal meeting was followed by an open house of the Department of Cinema.

For the June meeting, the last before the summer vacation, the Pacific Coast Section enjoyed an evening at NBC, Burbank, on June 23, 1953. NBC's new and modern plant is located on a 48-acre property which provides considerable space for future expansion. Two large audience studios are already completed, and there are two large rehearsal halls and a modern Production Services building containing several interesting innovations. Due to the broad interest of this program, members were invited to bring guests, resulting in the second largest meeting of the year, with 460 in attendance.

A. H. Saxton, Technical Network Operations Manager, welcomed the group and exhibited a 35mm kinescope recording. "A New 35mm Single Film System Kinescope Recording Camera" was described by Ralph E. Lovell, Kinescope Recording Supervisor. The first production model was shown, containing many interesting features. Marvyn S. Adams, Technical Operations Supervisor, spoke on "Technical Operating Facilities of the Burbank Studios," describing many of the special interlocking, automatic and interconnecting features which have been provided to meet present needs and to provide maximum flexibility for future requirements. A large screen theater TV unit for audience viewing was demonstrated. Special features of "Staging Services at the Burbank Studios" were described by R. Don Thompson, Manager of Television Staging Operations.

A tour of the entire NBC installation in Burbank followed the formal program.—*Philip G. Caldwell*, ABC Television Center, Hollywood 27, Calif.

Photographic Technology and BS Degrees

The Department of Photographic Technology at the Rochester Institute of Technology has built up a considerable reputation since it was founded in 1930, and at the present time stands high among schools of this kind. Two-year courses, including Processes of Color Photography are available, leading to the Associate in Applied Science degree. The New York State Board of Regents has approved plans which the Institute expects to have in effect so that students entering this Fall can begin study toward a bachelorate degree. Of about 100 students graduated yearly, several begin a career in some phase of motion-picture work. So far there have been no specific courses in motion-picture photography available, but tentative plans are being made to incorporate a major course in this field a year from now.

Journals in Two Parts

PART II of this *Journal* has the complete roster of the papers from the Screen Brightness Symposium held at the recent Los Angeles Convention. Reprint copies of this symposium are available from Society headquarters at $1.00 each.

Next month's *Journal* will also have a Part II, comprised of all those Los Angeles Convention manuscripts now available and having to do with stereophonic principles and equipment. Also included are three articles about basic development and the principles of auditory perspective, reprinted from a symposium in the *Bell System Technical Journal* for April 1934 and *Electrical Engineering* for January 1934. Single copies of this material are expected to be available at $1.00 each.

Book Reviews

The Science of Color

Committee on Colorimetry of the Optical Society of America, L. A. Jones, Chairman. Published (1953) by Thomas Y. Crowell, 342 Fourth Ave., New York 16. i-xiii + 340 pp. + 22 pp. references + 23 pp. glossary-index. 102 color plates + 40 tables + 102 illus. 7 × 10 in. Price $7.00.

The information contained in *The Science of Color* is background information which the good color technologist in any field should have. For this reason, the book is highly recommended for graduate study and research work.

The Science of Color can be divided roughly into three general sections: physical, psychophysical and psychological. Two chapters are devoted to physical information. One discusses radiant energy and its measurement and describes the behavior of light as it strikes matter and is transmitted or absorbed. This type of information is useful in understanding how light is modified by selected absorption and thereby becomes colored. Another chapter is devoted to the anatomy of the eye and physiology of color vision. This chapter gives a description of the construction of the eye and its various component parts and is useful in understanding the perception of color.

The psychophysical aspects of color involve the measurement of the color properties of an object and of light in order to determine the color effect the light will have upon an observer. Three chapters are devoted to this extensive subject. It is by the methods of measurement described in this section that the engineer is able to evaluate the color of objects he fabricates.

In the psychological section, one chapter is devoted to the sensory aspects of color and discusses such things as after-images and color discrimination. Among many other interesting facts it is pointed out that color discrimination in children improves rapidly up to the age of 25 years and is followed by a gradual falling off which becomes more pronounced around the age of 65. Another chapter is devoted to the perceptual and affective aspects of color. One of the many subjects discussed here is the mode of appearance, and we learn for instance that when an artist partially closes his eyes to evaluate color perception better he is endeavoring to separate color from object perception and is in effect changing the mode of appearance from a surface color to a film color. Also in this chapter we learn that in motion pictures the "mood" of a story can be maintained for a long sequence simply by continuing the dominant color.

The book is unique in that it includes a glossary index in which a large number of color terms are defined and reference given to sections of the book where the subject is discussed.

The technologist or engineer who in his daily work is handling materials to produce pleasing colors may be disappointed in the book in that it does not deal with the technology of color. When an engineer thinks of color, he is very likely to think of the limited aspects of producing colored films, colored television screens or colored objects—which is color technology. Actually the science of color embraces a large number of fields and consists of all knowledge concerning the production of color stimuli and their visual perception. The book quite properly includes all these aspects. If the engineer reads this book with the idea of getting background knowledge in order to understand better many of the color phenomena which arise in his daily work, he will find it well worth while.—*E. I. Stearns*, American Cyanamid Co., Calco Chemical Div., Bound Brook, N.J.

"Color"

From Germany comes an announcement of a new journal entitled *Color*, to be concerned with all aspects of color photography, colored light, color vision and its testing and color sensitometry. The Board of Editors includes some of the foremost authorities in Germany, such as Manfred Richter, E. Engelking, A. Kohlrausch, S. Rösch and J. Eggert. The journal is to appear in occasional numbers at 7.80 German marks per number. Full information can be obtained from the Verlag für angewandte Wissenschaften G.m.b.H., Rheinstrasse 79, Wiesbaden.

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1952 MEMBERSHIP DIRECTORY.

Honorary (**H**) Fellow (**F**) Active (**M**) Associate (**A**) Student (**S**)

Arthur, James K., Northwestern University **Mail:** 8916 Skokie Blvd., Skokie, Ill. (**S**)

Bernstein, Robert, Television Engineer, American Broadcasting Co. **Mail:** 683 Bradford St., Brooklyn 7, N.Y. (**A**)

Brossok, William C., Westrex Corp. **Mail:** 160 Beach St., Staten Island 4, N.Y. (**A**)

Buck, Peter J., Production Engineering Manager, Westrex Corp. **Mail:** 180 Prospect St., East Orange, N.J. (**A**)

Budd, E. R., Assistant Manager, B. F. Shearer Co., 1964 South Vermont Ave., Los Angeles, Calif. (**A**)

Burton, Don, Radio and Television Station Manager, Tri-City Radio Corp., P.O. Box 271, Muncie, Ind. (**M**)

Cahill, Don, Producer, Photographer. **Mail:** 5707 W. Lake St., Maywood, Ill. (**A**)

Chavvaria N., Alvaro, Apartado #1923, San Jose, Costa Rica, Central America. (**A**)

Chesnes, Albert A., Manager, Television Operations, Paramount Pictures Corp. **Mail:** 45-21—76 St., Elmhurst, N.Y. (**M**)

Clay, John P., Engineering Supervisor, WSAZ-TV. **Mail:** 3034 Third Ave., Huntington, W. Va. (**M**)

Conviser, Benjamin S., Executive, American Theatre Supply Corp., 78 Broadway, Boston 16, Mass. (**M**)

Cook, Lewis Clark, Technical Director, Central Illinois Telefilms, 810 North Sheridan Rd., Peoria, Ill. (**M**)

Cornberg, Sol, Supervisor of Plant and Facilities Development, National Broadcasting Co., Inc., 30 Rockefeller Plaza, New York, N.Y. (**M**)

Edison, Edward, Television Engineer, National Broadcasting Co. **Mail:** 329 Sycamore Rd., Santa Monica, Calif. (**M**)

Elliott, Lt. Col. Robert D., Motion-Picture Technical Staff Officer, U.S. Air Force. **Mail:** 12242 Magnolia Blvd., North Hollywood, Calif. (**M**)

Evans, William E., Jr., Television Research Engineer, Stanford Research Institute, Stanford, Calif. (**M**)

Fisher, Frank H., General Manager, J. Arthur Rank Film Distributor (Canada) Ltd., 277 Victoria St., Toronto, Canada. (**A**)

Goodman, R. Irwin, University of California at Los Angeles. **Mail:** 737 Burchett St., Glendale 2, Calif. (**S**)

Graziano, Peter S., Motion-Picture Printer Operator, Cinecolor Corp. **Mail:** 3013 West Via Ceizro, Montebello, Calif. (**A**)

Gregory, Howard P., Vice-President, Wilbur Machine Co., Inc., 50 Wall St., Binghamton, N.Y. (**M**)

Grube, Wolfgang Otto, Project Engineer, Research and Development Division, Mergenthaler Linotype Co. **Mail:** 130 Harcourt Ave., Bergenfield, N.J. (**A**)

Hagenau, Scott N., Assistant Chief Engineer, WSBT, WSBT-TV, 225 West Colfax Ave., South Bend 26, Ind. (**A**)

Hansen, William E., Film Technician, Acme Film Laboratories. **Mail:** 3369 Rowena Ave., Los Angeles 27, Calif. (**M**)

Hoyle, Peter I., Sound Engineer, Information Services Dept., Gold Coast Film Unit, P.O. Box 745, Accra, Gold Coast, West Africa. (**A**)

Janetis, Michael, Motion-Picture Cameraman. **Mail:** 100 W. 80 St., New York, N.Y. (**A**)

Jordan, Thomas E., Jr., Senior Motion-Picture Specialist, U.S. Air Force. **Mail:** 545 South St., Glendale 2, Calif. (**A**)

Kane, Henry S., President, North American Screw Products Co., Inc. **Mail:** 1732 North California Ave., Chicago, Ill. (**M**)

Kavlin, Marcos, Kodak Dealer, Casilla 500, La Paz, Bolivia. (**A**)

Kubicka, Heinz F., Chief Engineer, Television Advertising Association, Inc. **Mail:** 530 Riverside Dr., Apt. 1C, New York 27, N.Y. (**A**)

Leiby, Alden M., Chief Engineer, Franklin Electronics, Inc. **Mail:** 7926 Burholme Ave., Philadelphia 11, Pa. (**M**)

Levy, George M., Jr., Photo Patrol, Cine Speed, Inc., Roosevelt Raceway, Westbury, Long Island, N.Y. (**M**)

Locanthi, Bart N., Research Engineer, Acoustical Consultant, Cal-Tech, J. B. Lansing Sound Co. **Mail:** 2552 Boulder Rd., Altadena, Calif. (**M**)

Morrison, James C., University of California at Los Angeles. **Mail:** 6948 Cedros Ave., Van Nuys, Calif. (**S**)

Morrison, William A., Sales, Magnetic Sound Products, Reeves Soundcraft Corp., 10 E. 52 St., New York 22, N.Y. (**A**)

Muncheryan, Hrand M., Staff Physicist, Aerojet Engineering Co. **Mail:** 1202 Sesmas St., Duarte, Calif. (**A**)

Nicholson, Elwood J., First Cameraman, Director of Photography, Cinematic Production Service, 1123 Lillian Way, Hollywood Calif. (**M**)

Niles, Fred A., Vice-President, Director of Motion-Picture-Television Division, Kling Studios, Inc., 601 North Fairbanks Ct., Chicago 11, Ill. (**M**)
Norman, J. E., West Coast Manager, De Vry Corp., 5121 Sunset Blvd., Hollywood 27, Calif. (**M**)
Orrett, William S., Radio Engineer, International Productions, Ltd. **Mail:** Wexford P.O., Ontario, Canada. (**A**)
Palys, Frank, Photo Supplies, 207 Third St., Elizabeth, N.J. (**A**)
Patterson, Stanley, President and Partner, Pampa Electronics Sales Corp. **Mail:** 1380 Dermond Rd., Drexel Hill, Pa. (**M**)
Regal, Frank R., Film Technician, Warner Bros. Studio. **Mail:** 302½ Hollywood Way, Burbank, Calif. (**A**)
Ridinger, H. J., Jr., Television Technician, KLAC-TV. **Mail:** 11808 South Ruthelen, Los Angeles 47, Calif. (**A**)
Ronson, Harry A., Television Workshop of New York. **Mail:** 1510 E. Fourth St., Brooklyn 30, N.Y. (**S**)
Salas-Porras, Francisco, Assistant Manager, Azteca Films, Inc. **Mail:** 6102 Flores Ave., Los Angeles 56, Calif. (**A**)
Saxon, Spencer D., Motion-Picture Photographer, Audio-Visual Center, Syracuse University, Collendale at Lancaster, Syracuse 10, N.Y. (**A**)
Scales, John W., Chief Projectionist, Columbia Pictures Corp. **Mail:** 11622 Hamlin St., North Hollywood, Calif. (**M**)
Schwab, Don R., Film Producer, Sportsvision, Inc. **Mail:** 550 Veteran Ave., Los Angeles 24, Calif. (**M**)
Signaigo, Frank K., Research Director, E.I. du Pont de Nemours & Co., Photo Products Dept., Wilmington, Del. (**M**)
Snyder, J. Earl, Sound Mixer, Ryder Sound Service. **Mail:** 4755 Columbus Ave., Sherman Oaks, Calif. (**M**)
Stableford, John, Projection Equipment Manufacturer. **Mail:** 45 Latimer Rd., London W.11, England. (**A**)
Stickling, John H., Motion-Picture Projectionist, Starview Outdoor Theater, Inc. **Mail:** R.R. #2, Box 74, Dundee, Ill. (**M**)
Stratford, John, Executive Motion-Picture and Television Producer, Splendid Films, Inc. **Mail:** 2239 Savannah Ter., S.E., Washington 20, D.C. (**A**)
Tami, Joseph, Jr., University of California at Los Angeles. **Mail:** 3919 Third Ave., Los Angeles 8, Calif. (**S**)
Tate, John C., Printer Foreman, Acme Film Laboratories. **Mail:** 12208 Oxnard St., North Hollywood, Calif. (**A**)
Wallin, Walter, Optical Physicist. **Mail:** 20226 Arminta St., Canoga Park, Calif. (**A**)
White, Roy A., Television Engineer, Studio Supervisor, Paramount Television Productions, Inc. **Mail:** 913 North Frederic, Burbank, Calif. (**A**)
Wiener, Alan J., Manager, Visual Advertising Associates TV. **Mail:** 24 Lyons St., New Britain, Conn. (**A**)
Wright, Walter W., Design Engineer. **Mail:** 1822 Essex Ave., Linden, N.J. (**A**)
Young, Blanche, University of Southern California. **Mail:** 711¾ W. 35 Pl., Los Angeles 7, Calif. (**S**)

CHANGES IN GRADE

Buxbaum, Morton L., (**S**) to (**A**)
Clarke, Charles G., (**A**) to (**M**)
Dodge, Glenn T., (**S**) to (**A**)
Moorhouse, Anson C., (**A**) to (**M**)
Sarber, Harry, (**A**) to (**M**)
Sloan, Melvin, (**S**) to (**A**)
Woolsey, Ralph A., (**A**) to (**M**)

DECEASED

Harvey, Douglas G., University of Southern California. **Mail:** 1846 South Cochran Pl., Los Angeles 19, Calif. (**S**)
Oakhill, Frederic E., President, Prismacolor Pictures, Inc. **Mail:** 711 Linden Ave., Wilmette, Ill. (**M**)

SMPTE Lapel Pins

The Society has available for mailing its gold and blue enamel lapel pin, with a screw back. The pin is a ½-in. reproduction of the Society symbol — the film, sprocket and television tube — which appears on the *Journal* cover. The price of the pin is $4.00, including Federal Tax; in New York City, add 3% sales tax.

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April *Journal*.

Chemical Corner

Edited by Irving M. Ewig for the Society's Laboratory Practice Committee. Suggestions should be sent to Society headquarters marked for the attention of Mr. Ewig. Neither the Society nor the Editor assumes any responsibility for the validity of the statements contained in this column. They are intended as suggestions for further investigation by interested persons.

German Developing Machines The Union Color Developing Machine constructed for both the new negative/positive color processes and black-and-white is a low-cost machine reported capable of turning out twice the footage of our previous machines. Of duplex design, it can be had with 35mm or 16mm on each side or a combination of these. The drive mechanism is at the bottom and the film is transported by friction rollers. The tanks are lined with a thermoplastic material which is completely noncorrosive in the strongest bleach. The temperature of the solutions is controlled by heat exchangers located in the tanks themselves. The agents are Movie Technicians, 55 Poplar Ave., Hackensack, N. J.

Regeneration of Ferricyanide Bleach Baths U.S. Patent 2,611,699 makes claims for another scheme of the conversion by bromine of ferrocyanide back to the active ferricyanide and also supplies additional bromide in the process. The bromine is added in the required quantity as determined by analysis in the form of a hypobromite or of a bromate.

Hazardous Chemicals in Photography With the recent increase in the chemical activity in the motion-picture laboratory arising from color, 3-D and other new processes, a timely article in the *British Journal of Photography*, October 8, 1952, pp. 380-81, deals with dangerous chemicals that may be encountered in photography. Allergic reaction to chrome salts, developing and cleaning agents, especially the chlorinated ones near a glowing cigaret or flame hazards are mentioned along with other dangers which may be expected in experimental laboratories and darkrooms.

Sepia Tone Control Claims are made in U.S. Patent 2,607,686 for controlling the coldness of sepia tones by the adjustment of the bromide content of the developer. The higher the bromide the colder the tone.

Another Approach to Silver Recovery and Fixer Rejuvenation At the Naval Air Station at Anacostia, D.C., exhausted fixer is collected in a storage tank. When the liquid reaches a certain level an electrolytic silver recovery unit is automatically started. Ten stainless-steel cathodes collect the silver while the treated bath, which is rejuvenated at the rate of 90 gal/hr, is tested, readjusted and mixed with 20% fresh solution. A more complete description of this process is given in *American Photography*, December 1952, p. 12.

A Transparent Pipe Mills 111 is a transparent plastic pipe of cellulose acetate butyrate ranging in size from ½ to 4 in. It permits observation of processes and is highly resistant to attack by chemical solutions. Pipe sections are joined by a solvent cement that produces a leakproof homogeneous bond. No threading or special tools are required and it is cut with a hand saw. Setups may be dismantled and all components used repeatedly. The tubing is tough, shatterproof and requires a minimum of support. The manufacturer is Elmer E. Mills Corp., 2930 North Ashland Ave., Chicago 13, Ill.

A Greaseless Grease "Molynanul" is a molybdenum disulfide enamel which can be brushed or sprayed on any surface to give a very thin film lubricant. It puts a lustrous, hard, greasy-feeling but clean, coating from a fifth to a half-thousandth of an inch thick. Except in extreme cases normal clearances need not be disturbed as the final thickness is no greater than the allowance for oil. Its applications are numerous and might be investigated as a lubricant for motion-picture film. The manufacturer is The Lackrey Company, Southampton, N.Y.

New Products

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products.

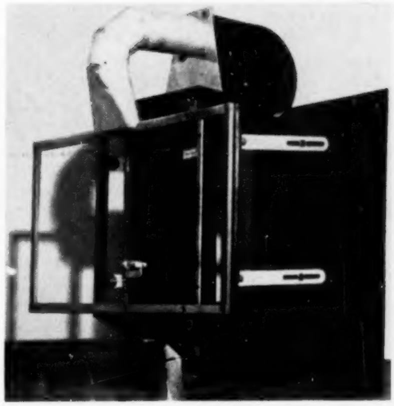
The first commercial production in the U.S. of optical-quality fused quartz intended for use in electronic computers, scanners, etc., is announced by Hanovia Chemical & Mfg. Co. The new quartz will be manufactured by Optosil Inc., Hillside, N.J., a newly formed subsidiary of Hanovia.

A major electronic application of Optosil quartz will be for ultrasonic solid delay lines whose function is to create a time delay of electrical impulses for predetermined periods. In such delay lines, the electromagnetic waves are first converted to ultrasonic waves through a piezoelectric transducer. These amplitude-modulated ultrasonic waves are then passed through a quartz medium, after which they are reconverted to an electrical signal whose modulation is identical with the input. Because of the ratio of 100,000:1 between the velocity of the electromagnetic waves and that of the sonic waves in the quartz medium, a significant time delay results. Relatively long delay periods in a small space can be produced by the use of multiple reflection paths (in two or three dimensions) within the quartz medium.

In the optical field, the new company will be prepared to supply the requirements of a variety of laboratory and commercial needs to which optical-quality fused quartz is suited. Among these are precision lenses, optical flats, projection lenses which operate under conditions of great heat and thermal shock, and any optical equipment which must transmit a high degree of ultraviolet radiation.

An electric film timer, tradenamed the Camart, has been designed and marketed by The Camera Mart, Inc., 1845 Broadway, New York 23, N.Y., for use in motion-picture editing, dubbing, narration, script timing and commenting. The unit will read elapsed time in minutes and tenths and will record total footage for 16mm or 35mm motion-picture film. The timer may be wired to the projector or recorder to start automatically, or may be used independently. It may be started and stopped any number of times, and the time or footage indicators may be reset separately. The mechanism is removable from the chassis for mounting in a rack assembly. Dimensions are 4½ in. high by 4½ in. wide by 7½ in. long, weight 4 lb. A combination timer for either 16mm or 35mm footage with time indicator is priced at $125. A combination 16mm and 35mm footage counter is also priced at $125. A single 16mm or 35mm footage counter sells for $75

A new filter alignment and cooling mechanism has just been put into production by the Drive-In Theatre Mfg. Co., Division of DIT-MCO, Inc., 505 W. Ninth St., Kansas City 5, Mo. The metal housing is designed to be mounted permanently at the porthole. The dimensions of the entering and leaving sides are sufficient to accept the wide projection beam of CinemaScope and Cinerama. The depth is such that it will not interfere with the projector, even at extreme angles, or with large magazines. The top plate of the housing is flat for blower mounting, and the bottom plate is sloped down at a 25° angle, to accept projection beams up to this angle. Where the need is for a greater pitch, any angle can be made. The blower has a capacity of 100 cfm with a 3050-rpm motor. The duct and spreader are metal, and the spreader is designed to distribute air over the entire surface of the filter. The framing mechanism is designed so that, after proper



alignment of the filter, it can be permanently locked to that alignment. The eight adjustments for the filter are in and out; up and down; top or bottom in and out at angles; right and left angles to horizontal.

Employment Service

These notices are published for the service of the membership and the field. They are inserted for three months, and there is no charge to the member.

Positions Wanted

Experienced motion-picture production man desires connection with film company as producer-director or production manager. During past 12 yrs. experience includes directing, photographing, editing, recording and processing half-million feet finished film, including educational films, industrials, TV spots, package shows for TV and experimental films. University graduate, married, twenty-nine years old; good references. Locate anywhere continental U.S. Write Victor Duncan, 8715 Rexford Drive, Dallas 9, Tex.

Film Production/Use: Experienced in writing, directing, editing, photography; currently in charge of public relations, sales and training film production for industrial organization. Solid film and TV background, capable administrator, creative ability, degree. References and résumé upon request. Write FPF, Room 704, 342 Madison Ave., New York 17, N.Y.

Positions Available

Wanted: Optical Engineer for permanent position with manufacturer of a wide variety of optics including camera objectives, projector, microscope and telescope optics, etc. Position involves design, development and production engineering. Send résumé of training and experience to Simpson Optical Mfg. Co., 3200 W. Carroll Ave., Chicago 24, Ill.

Wanted: Personnel to fill the 4 classifications listed below, by the Employment Office, Atten: EWACER, Wright-Patterson Air Force Base, Ohio:

Film Editor, GS-9: Must have 5 yrs. experience in one or more phases of motion-picture production. Experience must include at least 1½ yrs. motion-picture film editing with responsibility for synchronization of picture, narration, dialogue, background music, sound effects, titles, etc. $5060 yr.

Photographic Processing Technician (Color) GS-7: 6 yrs. progressively responsible experience in motion-picture photography and/or photographic laboratory work, involving essential operation of film processing. Eighteen months of this experience must have involved processing of color film. $4205 yr.

Photographic Processing Technician (Black-and-White) GS-7: 6 yrs. progressively responsible experience in motion-picture photography and/or photographic laboratory work, involving essential operation of film processing. $4205 yr.

Photographic Processing Technician (Black-and-White) GS-5: 2½ yrs. progressively responsible experience in motion-picture photography and/or photographic laboratory work, involving essential operation of film processing. $3410 yr.

Meetings

Society of Motion Picture and Television Engineers, Central Section Meeting, Sept. 11 (tentative), WLW-D, Dayton, Ohio

Illuminating Engineering Society, National Technical Conference, Sept. 14–18, Hotel Commodore, New York, N.Y.

The Royal Photographic Society's Centenary, International Conference on the Science and Applications of Photography, Sept. 19–25, London, England

National Electronics Conference, 9th Annual Conference, Sept. 28–30, Hotel Sherman, Chicago

74th Semiannual Convention of the SMPTE, Oct. 5–9, Hotel Statler, New York

Audio Engineering Society, Fifth Annual Convention, Oct. 14–17, Hotel New Yorker, New York, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting, Oct. 15 (tentative), Chicago, Ill.

Theatre Equipment and Supply Manufacturers' Association Convention (in conjunction with Theatre Equipment Dealers' Association and Theatre Owners of America), Oct. 31–Nov. 4, Conrad Hilton Hotel, Chicago, Ill.

Theatre Owners of America, Annual Convention and Trade Show, Nov. 1–5, Chicago, Ill.

National Electrical Manufacturers Association, Nov. 9–12, Haddon Hall Hotel, Atlantic City, N.J.

Society of Motion Picture and Television Engineers, Central Section Meeting, Nov. 12 (tentative), Chicago, Ill.

The American Society of Mechanical Engineers, Annual Meeting, Nov. 29–Dec. 4, Statler Hotel, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting, Dec. 10 (tentative), Chicago, Ill.

American Institute of Electrical Engineers, Winter General Meeting, Jan. 18–22, 1954, New York

National Electrical Manufacturers Assn., Mar. 8–11, 1954, Edgewater Beach Hotel, Chicago, Ill.

Optical Society of America, Mar. 25–27, 1954, New York

75th Semiannual Convention of the SMPTE, May 3–7, 1954, Hotel Statler, Washington

76th Semiannual Convention of the SMPTE, Oct. 18–22, 1954 (next year), Ambassador Hotel, Los Angeles

77th Semiannual Convention of the SMPTE, Apr. 17–22, 1955, Drake Hotel, Chicago

78th Semiannual Convention of the SMPTE, Oct. 3–7, 1955, Lake Placid Club, Essex County, N.Y.

The Seventh Congress of the International Scientific Film Association will be held September 18–27 in the National Film Theatre and Royal Festival Hall, London S. E. 1. A Scientific Film Festival will be held, and in addition, meetings will be held by the Permanent Committees on Medical, Research, Technical and Industrial Films. There will be special sessions on the technique and application of films in medicine.

Society of Motion Picture and Television Engineers

40 West 40th Street, New York 18, N. Y., Tel. LOngacre 5-0172
Boyce Nemec, *Executive Secretary*

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OF THE

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JOURNAL OF THE SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

SMPTE

SCREEN BRIGHTNESS SYMPOSIUM

Brightness Spot Meter • Carbons

Picture Quality

Viewing 16mm Prints • Stray Light

THIS ISSUE IN TWO PARTS
Part I, August 1953 Journal
Part II, Screen Brightness Symposium

AUGUST 1953

Society of Motion Picture and Television Engineers
JOURNAL ***VOL. 61*** ***AUGUST 1953*** ***NO. 2***

Screen Brightness Symposium

From the SMPTE 73d Semiannual Convention

PART II OF THE AUGUST 1953 JOURNAL

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Foreword
Screen Brightness Symposium

By W. W. LOZIER, *Chairman, Screen Brightness Committee*

THE FOLLOWING five papers were presented at the Los Angeles Convention of the Society this year as the second of a series of symposia sponsored and arranged by the Screen Brightness Committee. The first symposium was held just two years earlier, at the Spring Convention of the Society in New York, and was published in the September 1951 *Journal*.

For many years your Screen Brightness Committee has been urging members of the SMPTE and the companies and organizations with which they are affiliated to contribute fundamental information on the problems of viewing projected pictures. Surprisingly little published information is available for the guidance of engineering committees, and many questions must be tabled for lack of pertinent data. Especially has the Committee urged that private research on subjects having any bearing on the problems of projected pictures be reviewed with the intent to publish whenever possible. In several cases this policy has already furnished us with a number of excellent papers.

One very important aspect of motion-picture projection is the measurement of the screen brightness. The paper by Frank F. Crandell describes a new meter which promises to be of great usefulness for measurement of the brightness of all types of motion-picture screens, making it a simple matter to read or record the brightness of any portion of the motion-picture screen from any part of the theater.

The paper by F. P. Holloway, R. M. Bushong and W. W. Lozier reports on the capabilities of a number of combinations of experimental and standard projector carbons and lamps for projection of motion pictures. Reference is made to the newer motion-picture developments, such as outdoor theaters, three-dimensional motion pictures and wide theater screens.

The Screen Brightness Committee is especially grateful to the Eastman Kodak Company for releasing the results of three investigations — all originated to answer specific internal questions, but released because they usefully advance the art of projected pictures. The information is especially important to us today, when several segments of the industry have been inquiring about the effects of screen brightness upon quality and seeking to reconcile the requirements of showmanship with the limitations of technical advances.

The paper by L. D. Clark examines for black-and-white photography the relationship between picture quality and screen brightness when each print has been especially made for optimum quality at the brightness at which it is considered. In other words, if for

comparison we should choose a series of screen-brightness standards ranging from 5 to 80 ft-L, and then make the best possible print for each standard, which of the standards would we choose as capable of producing the best picture quality?

The paper by L. A. Armbruster and W. F. Stolle has a different objective — how does the brightness of a laboratory's review-room screen influence the quality of 16mm Kodachrome prints that laboratory will produce? Two controls are available: the laboratory can advise the customer how to expose his original and the laboratory can choose the timing of its print. The resulting prints are intercompared and judged for quality at screen brightnesses of 2 to 45 ft-L, and the laboratory opinion of its print is compared with the results when all are viewed at the standard level of 9 to 14 ft-L.

The paper by R. L. Estes considers the importance of controlling stray light if the screen illumination is to be used to best advantage. Stray light is shown to be especially important as screen brightness is reduced, rapidly reaching the point where stray light alone controls the quality of the image. This work has a two-fold significance, for on the one hand several standardizing bodies in other countries are proposing for our consideration limitations on the stray light on projection screens, and on the other several recent developments in projection practice are currently limited to lower brightness levels where stray-light control is most important. It is most unfortunate that everyone could not see the demonstration by Mr. Estes at the Los Angeles meeting of the effects of various amounts of stray light on the projected picture. This demonstration clearly showed the undesirable influence on picture quality of more than 0.3% stray light.

The Committee believes that these papers represent only a fine beginning. The data presented here should be considered in the formulation of Engineering Committee recommendations and standards. The Committee hopes that these papers will be followed by many further studies on these and related subjects in order to enhance still further our knowledge of the ways of obtaining more effective presentation of motion pictures. In this way, motion-picture technology can advance soundly.

New Photoelectric Brightness Spot Meter

By FRANK F. CRANDELL and KARL FREUND

A new photoelectric brightness meter covering an angle of only 1½° and measuring brightness from 0.1 ft-L to 1,000,000 ft-L is described. Applications such as its use in measuring screen brightness for standard and 3-D projection screens are discussed.

THE FIRST photometer is generally attributed to Pierre Bouguer in 1729[1] (Fig. 1); however, in a book published in 1613 in Antwerp by Francis Aguilon[2,3] more than a hundred years earlier, one of the few books incidentally which was illustrated by the great Flemish painter Peter Paul Rubens, there is portrayed in one of the illustrations a photometric experiment with apparatus nearly identical to that described by Bouguer (Fig. 2). In the illustration the two cherubs are helping the scholar perform the experiment. The light from the single lamp comes through the far aperture onto the screen. The light coming from the double lamp shines onto the screen through the near aperture and the second cherub is placing this brighter lamp farther away from the screen in order to produce a spot of equal brightness. Aguilon's book also contains the earliest known reference to "stereographic projection."

Variations of the "brightness matching" method have been used down through the years as the only means of photometric measurement. Improvements that increased the ease and accuracy of the measurement were made. Ritche in 1826[4] used a wedge to bring the two comparison areas next to each other, a requirement for greater accuracy. R. Bunsen in 1843[5] devised the first really accurate photometer known as the "grease spot photometer" which used a piece of thin opaque white paper with a translucent spot produced by treating the paper locally with oil or wax. The unknown light was placed on one side

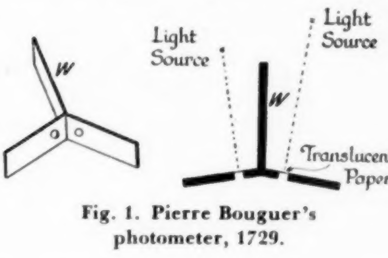

Fig. 1. Pierre Bouguer's photometer, 1729.

Presented on April 29, 1953, at the Society's Convention at Los Angeles by Frank F. Crandell (who read the paper) and Karl Freund, Photo Research Corp., 127–129 W. Alameda Ave., Burbank, Calif.
(This paper was received May 20, 1953.)

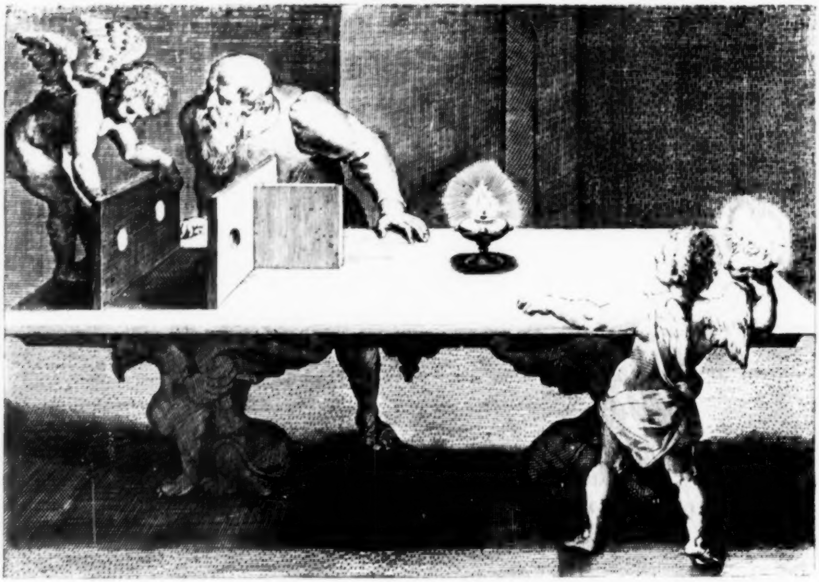

Fig. 2. Photometer illustrated by Peter Paul Rubens in a book by Francis Aguilon published in 1613.

of the paper and the comparison lamp on the other. Adjustment was made until the spot seemed to disappear. This took place when the brightness on the two sides of the paper just matched. In 1889 Lummer and Brodhun[6,7,8] introduced their "cube," composed of two right-angle prisms with portions of the common face of one prism etched away so that a pattern of total-transmitting and total-reflecting surfaces was produced.

However, all of these are only refinements of the principle so clearly portrayed by Rubens in 1613. They all depend on visual matching of two areas. One area is illuminated by the source to be measured, the other illuminated by the "standard source" and a matching produced by adjusting the distances and making the measurement by use of the inverse square law. Or the adjustment may be made by modifying one beam with a wedge, shutter, crossed polarizers, variable slit or the like, using the degree of modification as a measure of the illumination from the unknown source.

This matching becomes increasingly difficult the greater the difference in color between the two light sources. When a color difference is present different observers will obtain different matching points, and even the same observer will obtain varying results depending on the brightness and color of objects just previously viewed. These instruments can be used to measure surface brightness by imaging a small portion of the surface to be measured on one section of the comparison field. However, much greater deviations of color are encountered in the surfaces of objects than those encountered in light and it is the exception to find a surface that matches the color of the "standard source" in the photometer closely enough to be at all certain of the "matching" point.

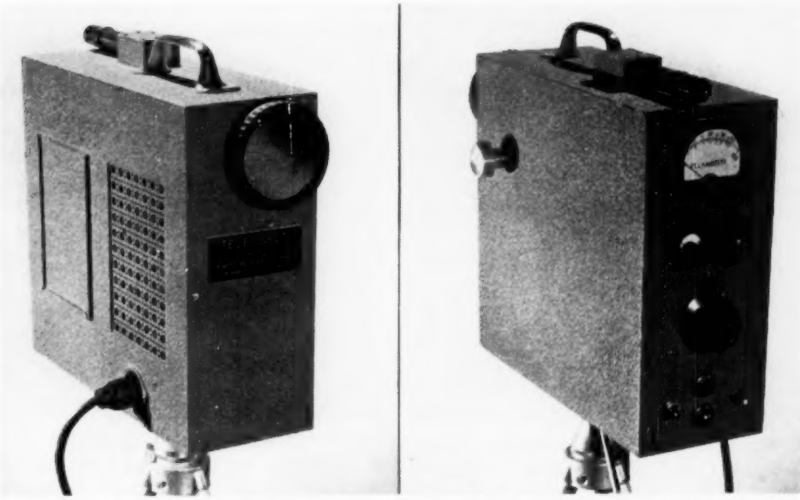

Fig. 3. First Spot Meter, a-c powered, weight 25 lb, range 1 to 1000 ft-L.

The relative sensitivity of the normal eye to light of different wavelengths has been determined by many different workers. In 1931 the International Commission on Illumination (ICI) specified the points on the luminosity curve to four significant figures. If a light-sensitive instrument is made to match this curve in sensitivity it will accurately duplicate the response of the eyes of the "standard observer" and not be limited by the need of matching widely different colors. This has been done with a fair degree of accuracy for the barrier photocell by covering it with a "Viscor" or similar filter. The sensitivity of this combination is sufficient to measure incident light down to a few footcandles and reflected light, received from the relatively wide viewing angle of from 30° to 120°, down to a few footlamberts. Its sensitivity is not sufficient to measure brightness over small viewing angles or low brightness levels.

Many inquiries have been received by Photo Research Corp. from various sources such as the SMPTE Screen Brightness Committee, illuminating engineers, television-tube manufacturers, airplane-instrument manufacturers, police departments and others regarding an instrument that would measure the brightness of small areas from a distance and still be sensitive enough to read down to a few footlamberts or less. In view of these inquiries Photo Research Corp. decided to look into the possibility of developing such an instrument.

The first solution was a rather elaborate optical system with a photomultiplier tube and associated electronic system requiring a-c line current to operate and weighing about 25 lb (Fig. 3). It covered a viewing angle of 1° and measured brightness from 1 ft-L to 1000 ft-L.

This was a step in the right direction but for most applications a light, portable, self-contained instrument was desired. Dr. William Baum of Palomar Observatories at Mount Wilson had done considerable work on small battery-operated circuits for the measurement of star brightness. By making the optical system more compact and by adapting the extremely sensitive stellar-photometer type of circuit, an instrument was developed which measured a wide range

Fig. 4. Spectra Brightness Spot Meter, weight about 5 lb, no external power required, range 0.1 to 1,000,000 ft-L.

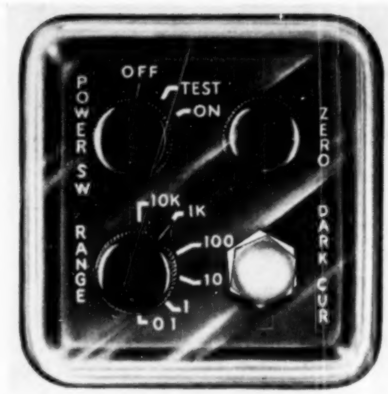

Fig. 5. Control panel of Spectra Brightness Spot Meter.

of brightness, required no external power source and weighed less than 5 lb.

The Spectra Brightness Spot Meter, as it is called (Fig. 4), is a direct-reading instrument with the extremely small acceptance angle of only $1\frac{1}{2}°$ and will measure brightness from 0.1 ft-L up to 1,000,000 ft-L. The optical system of the meter consists of a four-element $f/1.9$ lens in focusing mount which forms an image of the region to be measured on a reticule in the optical housing. A circle in the center of this plate indicates the exact extent of the area being measured. This image is viewed magnified through a telescopic eye-piece. A partial reflecting mirror just ahead of the reticule plate reflects a portion of the light downward to the phototube. An opaque aperture plate is located at the focus of this light beam directly above the phototube. This plate excludes all light except the portion of the image that corresponds to that within the circle of the reticule. The light emerging from this aperture passes through a filter wheel and then onto the cathode of the phototube. The output from the phototube passes through the resistor selected by the range switch (Fig. 5).

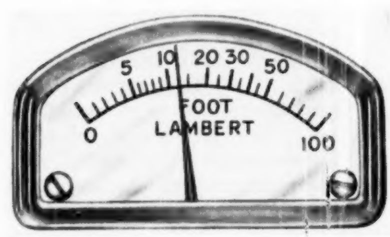

Fig. 6. Meter dial showing logarithmic-type scale having the same percentage accuracy over nearly the entire scale length.

The voltage produced in this resistor is duplicated with a current amplification of as much as one million times by a special electrometer tube amplifier. This output current is then read on a logarithmic response microammeter which is calibrated to read directly the footlambert brightness of the surface viewed (Fig. 6). The scale is calibrated from 1 to 100 ft-L. Range multipliers of 0.1, 1, 10, 100, 1000, and 10,000 are available on the range switch.

A locking-type microammeter is used so that readings may be held fixed as long as desired. This is particularly

useful when the meter is hand-held. The reading is captured by merely pushing and releasing the button on the side of the meter case. The reading is then retained until the button is again depressed.

When scanning with the instrument on a tripod the meter can be made to read continuously by merely depressing and then turning the button. The logarithmic scale makes the percentage accuracy approximately uniform over the entire length of the scale. Accuracy is better than five percent of reading over the entire range of sensitivity and is maintained throughout the life of the batteries.

A six-position filter wheel is incorporated in the instrument and is controlled by a knob located on top of the case (Fig. 7). The accuracy with which

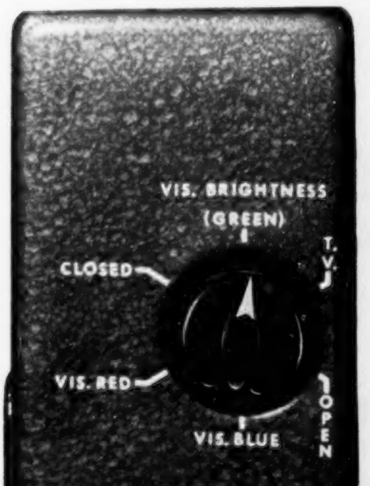

Fig. 7. Filter control knob on top of instrument. Neon flasher (lower left) indicates when instrument is turned on.

the sensitivity of the instrument matches the ICI luminosity curve when on the "visual brightness" position is indicated in Fig. 8. The "closed" position of the filter wheel completely excludes light from the phototube and is used when zeroing the instrument. A blue filter approximately matching the sensitivity to the ICI blue primary and a red filter confining the sensitivity to the red portion of the ICI red primary fill two of the remaining positions in the wheel. A filter approximately the sensitivity of the image orthicon and an open position that can be used with any external special filter completes the filter wheel. The relative amounts of red and blue light in different areas can be read with the corresponding filters in position.

With the addition of an adjustable iris, which mounts directly in the threaded ring in the front of the lens barrel, the Spectra Brightness Spot Meter can be supplied calibrated as a direct-reading color-temperature meter. With the red filter in position, the iris is adjusted until the needle of the microammeter comes to a red reference mark on the scale. The filter wheel is rotated to blue and color temperature or color index is read directly on the blue-red index scale. By rotating the filter wheel to green the green-red color index can be read on its corresponding scale. Where interest is primarily in how color films will respond to the light rather than its visual color, a special model of the Spot Meter is available with filters matched to the average response of the red-, green- and blue-sensitive portions of color film. The reading of a light source whose spectral distribution closely approximates a blackbody will be the same on both models of the instrument but, when light sources that differ widely from blackbodies are read, the two models will indicate different color indexes showing that these sources do not appear the same to the color film as they do to the eye.

A jack is mounted on the right side of

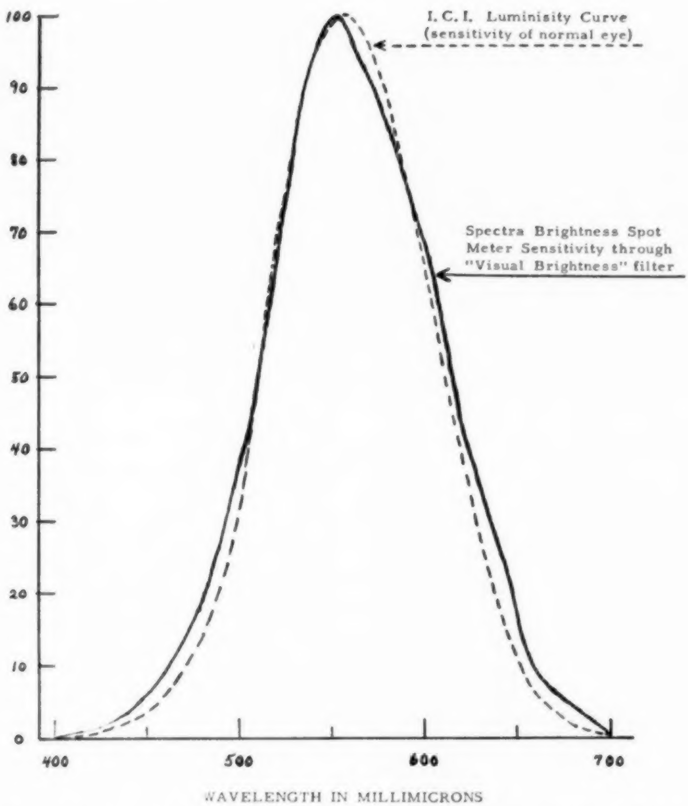

Fig. 8. Spectral response of Spectra Brightness Spot Meter on "Visual Brightness" position as compared with the ICI luminosity curve.

the instrument where an external meter or recorder can be plugged in (Fig. 9). A larger microammeter is available which can be plugged to this jack when greater accuracy is desired or for more rapid reading when two operators are available. One operator scans the scene while the second reads and records the results. Where a permanent continuous reading is desired, a recorder can be operated from this same outlet.

The lens barrel is engraved with a footage scale from 5 ft to infinity (Fig. 10). The lens can be focused on objects still closer, but error is introduced due to the increased focal distance. Where highest accuracy is desired, supplementary lenses should be used when reading areas closer than 6 ft. Five supplementary lenses are regularly available and others can be made to order. The first covers an area of $1\frac{1}{2}$ in. at 5 ft, a second covers 1 in. at 40 in., a third $\frac{1}{2}$ in. at 20 in., a fourth $\frac{1}{4}$ in. at 10 in., and the fifth is a four-element supplementary lens covering an area of $\frac{1}{16}$ in. in diameter at a little over 2 in. in front of the supplementary lens. Brightness of a very small area such as luminous marking on dials can be thus measured.

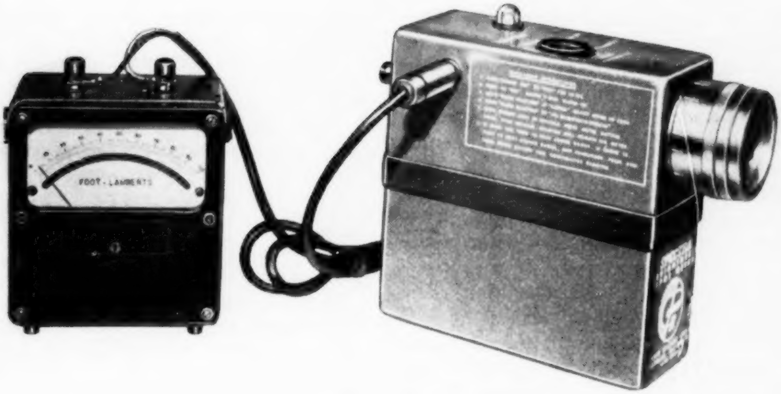

Fig. 9. Spectra Brightness Spot Meter with external microammeter.

The battery component (Fig. 11) which fits compactly in the base of the instrument is readily accessible and consists of six Mallory RM-12 $1\frac{1}{4}$-v cells, two Eveready No. 411 15-v cells, one No. 412 $22\frac{1}{2}$-v cell, and four No. 413 30-v cells. When the Spot Meter is to be used continuously for long periods of time at a single location an external power supply operating from 60-cycle line current may be used to replace the batteries.

An application of special interest to this Society, particularly with the present trend to wide screens, 3-D screens and the

Fig. 10. Focusing mount on pickup lens.

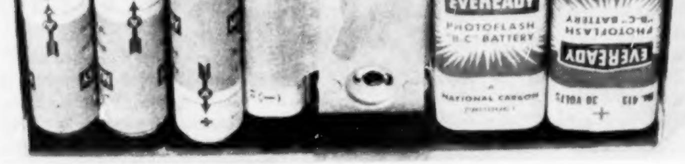

Fig. 11. Battery compartment as it appears with bottom cover removed. Batteries can be lifted out by pulling up on cloth tabs.

like, is its use in screen-brightness measurements. Being small, light and requiring no external power, it can be taken anywhere in the auditorium so that the screen brightness can be measured from any viewing angle. The small angle of view means that not only can the average brightness be read from each angle but the evenness of the light reflected in that direction over the screen area can be measured. If a patch of known reflectance and color of sufficient size to fill the angle of view of the Spot Meter is placed against the screen the footcandle level of illumination produced by the projector at the screen can be read. By comparing the readings of this standard patch with that of the screen measured through each of the primary color filters, the reflectance of the screen and amount of color modification produced by the screen can be measured.

A great many uses for the meter have already been suggested by the illuminating engineers, photographers and others who have used it. Doubtless many more will be added when the meter comes into more general use, for it is the first commercial instrument for measuring the brightness of small areas, with the errors inherent in visual methods eliminated.

References

1. Pierre Bouguer (1698–1758). Reprinted in *Les Maîtres de la Pensée Scientifique*, Paris, 1921.
2. *Francisci Aguilonii e Societate desu Opticorum Libri Sex Philosophis iuxta ac Mathematicis utiles*, Antwerp, 1613.
3. E. C. Watson, "Rubens as a scientific illustrator," *Am. J. Phys., 16:* 183–184, Mar. 1948.
4. *Trans. Roy. Soc. Edinburgh, 10:* 443, 1826.
5. R. Bunsen and H. E. Roscoe, *Phil. Trans., 149:* 891, 1859.
6. O. Lummer and E. Brodhun, "Ueber ein neues Photometer," *Zeitschrift für Instrumentenkunde, 9:* 41–50, 1889; *Journal für Gasbeleuchtung und Wasserversorgung, 32:* 421–424, 1889.
7. O. Lummer and E. Brodhun, "Lichtmessung durch Schätzung gleicher Helligkeitsunterschiede," *Zeitschrift für Instrumentenkunde, 9:* 461–465, 1889.
8. O. Lummer, "Ueber die photometrischen Arbeiten der physikalisch-technischen Reichsanstalt," *Journal für Gasbeleuchtung und Wasserversorgung, 32:* 767–775, 1889.

Discussion

Anon: Can the meter be used to measure the brightness of light sources?

Mr. Crandell: Two light sources can be compared by measuring how much of the light from each is reflected by any diffuse surface at the point in question. If a magnesium oxide standard is used for the reflecting surface, the meter will read directly in footcandles. Such a standard is available as an accessory to the meter.

Anon: What size is that?

Mr. Crandell: It's about 2 in. in diameter.

Anon: Secondly, in connection with the use of this meter for 3-D applications, what is the sensitivity of this instrument to polarized light? Would it be any different from its sensitivity to unpolarized light?

Mr. Crandell: No, the sensitivity would be only very slightly affected by the direction of polarization, since there is one reflection within the instrument and the amount of that can be measured and correction allowed for it. But the necessary correction would be small.

M. J. Merrick (Sawyer's, Inc.): Can this meter be used at the screen for measuring the difference in the illumination of various parts of a negative, by a small spot measurement of that kind?

Mr. Crandell: You mean with the picture on the screen?

Mr. Merrick: Yes, with the picture on the screen and measuring right at the screen.

Mr. Crandell: Screen-brightness measurements, of course, are usually done with no picture on the screen, to see how even the illumination is, not to get readings of portions of the picture.

Mr. Merrick: Yes, I realize that. I had in mind an application that comes up in our work quite often where we have need for a very small pickup to use right at the screen.

Mr. Crandell: If you can move in close enough to the screen so that the $1\frac{1}{2}°$ acceptance angle will cover only the area desired, then it can be done all right.

Recent Developments in Carbons for Motion-Picture Projection

By F. P. HOLLOWAY, R. M. BUSHONG and W. W. LOZIER

Performance data are summarized for various carbon-arc projection-lamp systems including carbon combinations commercially available for some years, as well as new ones recently introduced and also some experimental carbons not yet in use. Screen sizes that can be illuminated to various brightness levels are reported for the various carbon combinations both for conventional and also for stereoscopic 35mm motion pictures. Some consideration is also given to the requirements of wide pictures.

RECENT developments in the motion-picture field, such as outdoor theaters, three-dimensional motion pictures, wide-screen pictures and some forms of theater television have focused attention on carbon-arc light sources used for projection. In some instances, the projection light requirements have been greatly altered compared to conventional 35mm film projection. This paper will correlate the projection requirements of some of these new developments with the characteristics of various possible carbon-arc projection systems, including both standard combinations of lamps and carbons and also some experimental carbons for which completely suitable commercial lamps are not yet available.

A paper published in 1947 in this *Journal*[1] gave a complete summary of the amount of screen illumination which could be obtained with the popular combinations of lamps, optical systems and carbons used for 35mm motion-picture projection. The years since that earlier report have seen important new developments in all aspects of motion-picture projection systems. The 13.6-mm Hitex super high-intensity carbon was introduced in 1949 for use in rotating-type condenser lamps at 170 to 180 amp.[2] Recent months have witnessed the introduction of a new 13.6-mm standard high-intensity carbon to replace the former one used in condenser-type lamps at 125 to 150 amp. A new 9-mm Suprex positive carbon has extended the range and output of the nonrotating-type reflector lamp used with copper-coated, nonrotating carbons. A new 7-mm Suprex positive carbon has recently made possible increases in effi-

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(This paper was received on May 3, 1953.)

ciency and light output. New high-speed, reflector-type lamps employing rotating 9-mm and 10-mm positives have been marketed and find wide usage. In addition to these combinations already in commercial usage, there are some experimental possibilities not yet marketed. Detailed performance characteristics of some of these new combinations have not previously been published. These include new 9-mm and 10-mm Hitex carbons for rotating, reflector-type lamps and new 10-, 11- and 13.6-mm Ultrex carbons for use with effective water cooling for rotating, reflector-type as well as condenser-type lamps.

The basic performance data, as well as a description of the conditions under which they were obtained, are reported in the Appendix to this paper. These include screen light, screen-light distribution, radiant-energy flux at the film aperture and carbon-consumption rates at various arc currents.

Standard 35mm Motion Pictures

The data of Table II (see Appendix) have been used to calculate the widths of screens which can be illuminated to the ASA indoor theater brightness standards of 9 to 14 ft-L at the center of the screen based on the following conditions:

1. A projector shutter of 50% transmission.
2. A projection-room port glass of 90% transmission.
3. A projection screen of 75% reflection factor.

The resultant screen widths are shown in Fig. 1 for the various items of Table II, both at 80% side-to-center screen distribution and also at maximum light. No allowance has been made for light losses that may occur with heat filters which may be needed for a number of items to prevent heat-on-film troubles. The data of Fig. 1 will need to be correspondingly altered in case there are any additional light losses beyond those assumed. For example, a 10% loss in light will reduce the indicated screen widths about 5%.

On the basis of the light output levels reported in this paper, Fig. 1 shows that Suprex trims are capable of illuminating screens approximately 15 to 28 ft wide at 80% distribution and 16 to 30 ft wide at maximum light. The rotating-type reflector lamps increase these screen widths to 22 to 33 and 26 to 37 ft with standard carbons, and approximately 25 to 40 and 30 to 47 ft with experimental carbons. Generally speaking, the rotating-type condenser lamps are capable of illuminating approximately the same width screens as the rotating-type reflector lamps.

Outdoor Theaters

It is obvious from the foregoing discussion that under the conditions assumed, employing a matte screen of 75% reflection factor, it is impossible to light screens 50 to 70 ft wide, common in outdoor theaters, to the standards of 9 to 14 ft-L applicable to indoor theaters. However, the screen-brightness requirements of outdoor theaters are not as precisely known as are those for indoor theaters. Many successful outdoor theaters are operating with screen brightness substantially lower than those typical of indoor theaters. Just how large a screen can be illuminated with any given projection system will depend on just what level of screen brightness is desired. The data of Fig. 1 can be rendered applicable to lower screen-brightness levels by increasing the screen width ordinates appropriately corresponding to the decrease in screen brightness. For example, increasing the indicated screen widths by 50%, while keeping the picture proportions the same, corresponds to a screen area 2.25 times greater, which can be illuminated by the combinations of Fig. 1 to a center brightness of 4 to 6.2 ft-L. These screen-brightness limits have not been chosen because of their ultimate desirability for outdoor theaters, for it is certain that higher brightness would result in a better picture, but rather because they

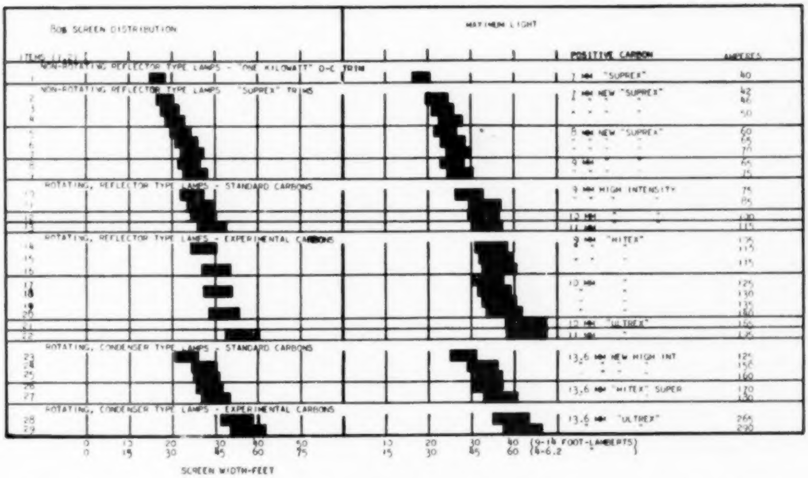

Fig. 1. Size of screens capable of illumination to indicated screen brightness (9–14 ft-L or 4–6.2 ft-L)[3] at center of screen with various projection systems.

Notes: 1. See Table II for details on items.

2. Items 11 to 22 and 24 to 29 may require heat filter and corresponding loss of light and decrease in screen width for indicated screen brightness.

3. Footlambert values assume: (A) 50% shutter transmission; (B) 90% projection port glass transmission; and (C) diffusing screen of 75% reflection factor.

are in the range being obtained by some outdoor theaters. By increasing the screen widths indicated in Fig. 1 by 50%, as done on the lower scale of Fig. 1, we see that the rotating-type reflector lamps and the rotating-type condenser lamps can illuminate screens 45 to 70 ft wide to screen brightnesses in the range of 4 to 6 ft-L.

Requirements of Three-Dimensional Motion Pictures

The stereoscopic motion pictures of the type being shown in this country employ separate lamps, projectors and 35mm films for the projection of right- and left-eye pictures, each polarized at right angles to the other, with reflection from a metallic-type screen and viewing through correspondingly oriented polarizing viewers. The light losses will depend upon the transmission of the various stereoscopic components. The components required beyond those for conventional motion-picture projection are:

1. Polarizers to polarize the right- and left-eye pictures.
2. Metallic-type screen which will not depolarize light.
3. Polarized viewers to separate the right- and left-eye pictures.

The reduction in light occasioned by conversion of any given projection system to stereoscopic projection will depend upon the transmission of the added stereoscopic components which in turn will depend upon the particular design and technical characteristics of these components. All that can be done in this discussion is to choose typical transmission values, realizing that these may be altered by future design changes during the evolution of stereoscopic motion-picture projection.

Present-day polarizing materials are reported to have a typical transmission value of 40%. The viewing spectacles are likewise reported to have a transmission of 80% for light polarized parallel to the axes of the spectacles. At the present time, the reflection factor of metallic-type screens suitable for stereoscopic motion-picture projection is more uncertain and subject to variation depending upon the particular type of screen employed. It has been a general characteristic that the metallic-type screen has an inverse relation between maximum screen reflection factor and uniformity of screen brightness over all angles of view in the theater. Consequently, a compromise is chosen between high screen reflection factor with undesirable directional variation on the one hand, and lower screen reflection factor, but with better directional characteristics, on the other.

A reflection factor of 125% is typical for a number of screens which have been used for stereoscopic projection; that is, the reflected screen brightness is 125% that of a perfectly diffusing and reflecting screen with equal incident illumination. Combining this screen reflection factor with the other components, it is possible to ascertain the effect of the stereoscopic optical system on the screen brightness as observed through the spectacles. The combination of this screen with the polarizer and the viewing spectacles will have an overall transmission of 40% ($1.25 \times 0.40 \times 0.80 = 0.40$) compared to the assumed 75% reflection factor for the matte screen used for conventional projection and for the data of Fig. 1. The stereoscopic projection components therefore reduce the final screen brightness to a value equal to 53% (40 divided by 75 = 0.53) of that with the same projection system with a matte screen without stereoscopic accessories. In other words, the stereoscopic accessories including a screen of 125% reflection factor reduce the resultant screen brightness to a value approximately half that for conventional projection with the same system. The fact that separate projectors are employed for the right- and left-eye pictures does not alter the basic facts of this analysis, for each projector is subjected to this approximately 50% loss in brightness and contributes only to the brightness and picture observed by one eye. The composite picture brightness visible to both eyes is still equal to that furnished by the individual projectors to each of the observer's two eyes. It should be realized that the above conclusions of this analysis will be altered in case a screen of other than 125% reflection factor is employed for stereoscopic motion pictures. If, for example, efforts to produce screens with higher reflection factor with adequate uniformity of brightness over the theater viewing angles are successful, then the figures of this analysis will be correspondingly altered.

On the basis of the foregoing conclusion that stereoscopic projection will result in 50% loss in picture brightness, one can estimate the output of light on various size screens by simple proportioning of the screen widths or screen brightnesses shown in Fig. 1. Accordingly, the indicated widths of screens could be illuminated to one-half the brightness values shown in Fig. 1. Alternatively, the various systems would illuminate screens approximately 70% of the widths shown in Fig. 1 to the same brightness levels employed there. Still another way of looking at the situation shows that two projection lamps, each having twice the lumen output shown in Table II for any of the items of Fig. 1. will be needed in order to produce equivalent brightness on the same size screen with stereoscopic projection.

Current practice with stereoscopic motion pictures using a single pair of interlocked projectors makes a long continuous period of operation desirable in order to minimize interruptions for rethreading projectors. Accordingly, consideration has been given to operating

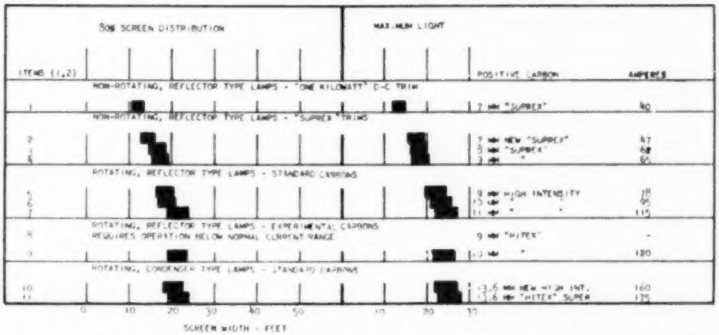

Fig. 2. Size of stereoscopic screens capable of illumination to 9–14 ft-L[3] at center of screen (based on operating conditions producing 1-hr minimum continuous operation).

Notes: 1. See Table I for details on items.

2. Items 5 to 11 may require heat filter and corresponding loss of light and decrease in screen width for indicated screen brightness.

3. Footlambert values assume: (A) 50% shutter transmission; (B) 90% projection port glass transmission; (C) 40% polarizer transmission; (D) 125% screen reflection factor; and (E) 80% viewer transmission.

conditions which will permit 1-hr minimum operation of the projection lamp without interruption. This is usually determined by matching the burning rate of the positive carbon to the available length of positive carbon travel permitted by the lamp. This is, in turn, a function of the lamp design and is subject to future change with lamp modifications now being considered. The values of positive carbon travel listed in Table I are typical of some present-day lamps. Ultrex carbons have been omitted from this consideration because no suitable commercial water-cooled lamps are available and, furthermore, the operating current to produce 1-hr life would be too far below the normal current range for these carbons.

The arc current necessary for each carbon trim to produce the required consumption rate to permit 1-hr life can be determined from Fig. 4. The screen lumen output of the projection lamp can then be read off at the indicated arc current from Fig. 3 or can be obtained more directly from Fig. 5 for the required consumption rate. The arc current, consumption rates and lumen output for 1-hr minimum operating time are given in Table I. It should be remembered that these screen lumen output values of Table I are the full output of the projection system undiminished by shutter, film, filters or any stereoscopic accessories. A combination of these lumen outputs with the transmission and reflection factors already described for stereoscopic projection, results in the screen widths which can be illuminated to the recommended 9 to 14 ft-L screen brightness range. These screen widths have been plotted on Fig. 2 for the various lamps and carbons which permit 1-hr operation. Under this limitation, the nonrotating reflector-type lamps employing either the "One Kilowatt" or the higher-current Suprex trims are limited to screens below 20 ft in width. The rotating-type reflector lamps should be restricted to screens smaller than approximately 25 ft in width. The rotating condenser-type lamps should likewise be limited to

Table I. Stereoscopic Motion-Picture Projection — Based on Operating Conditions for 1-Hr Minimum Continuous Operation.

Item	Positive carbon	Typical positive carbon travel,[1] in.	Amp	Positive consump. rate, in./hr	80% Dist. Screen lumens[2]	80% Dist. % dist.	Max. light Screen lumens[2]	Max. light % dist.
		Nonrotating, Reflector-Type Lamps — "One Kilowatt" d-c Trim						
1	7-mm Suprex	7¼	40	5.8	5,900	80	6,500	65
		Nonrotating, Reflector-Type Lamps — Suprex Trims						
2	7-mm New Suprex	10	47	10	8,400	80	10,500	60
3	8-mm Suprex	10	62	10	11,000	80	11,800	65
4	9-mm Suprex	10	65	(10)	12,300	80	13,000	70
		Rotating, Reflector-Type Lamps — Standard Carbons						
5	9-mm High-Intensity	16	78	16	13,500	80	16,800	60
6	10-mm High-Intensity	16	(95)	(16)	(14,000)	80	(18,500)	60
7	11-mm High Intensity	16	115	15	18,500	80	21,500	65
		Rotating, Reflector-Type Lamps — Experimental Carbons						
8	9-mm Hitex	16			Below normal current range			
9	10-mm Hitex	16	(120)	(16)	(18,500)	80	(21,500)	65
		Rotating, Condenser-Type Lamps — Standard Carbons						
10	13.6-mm New High-Intensity	18	160	17.5	(16,500)	80	20,500	60
11	13.6-mm Hitex Super	18	175	18	18,500	80	22,500	60

[1] Depends upon lamp design.
[2] Screen lumens without shutter, film, filters or stereoscopic accessories — same conditions as Table II.
Note: Values in parentheses are approximate.

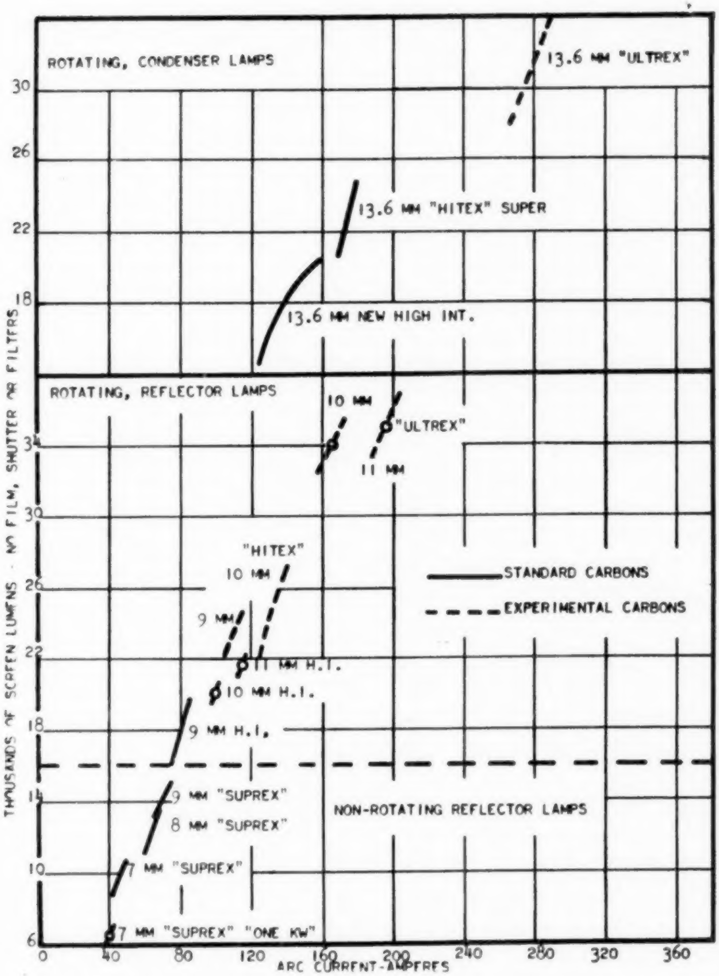

Fig. 3. Maximum screen light vs. arc current (see Table II).

screens approximately 25 ft in width to maintain recommended brightness. It should again be remembered that any light losses due to the use of heat filters or other means of reducing the heat at the film will make a corresponding reduction in the indicated screen widths in Fig. 2.′ For example, a loss of 10% in light would reduce the screen width by approximately 5%.

Removal of the limitation of 1-hr operation would permit the use of all carbons at their maximum operating current listed in Table II, where in each case they would produce at least 20 min continuous burning and would project a standard 1800-ft reel. This would increase the light from some of the more powerful trims sufficiently to permit an increase in screen width of

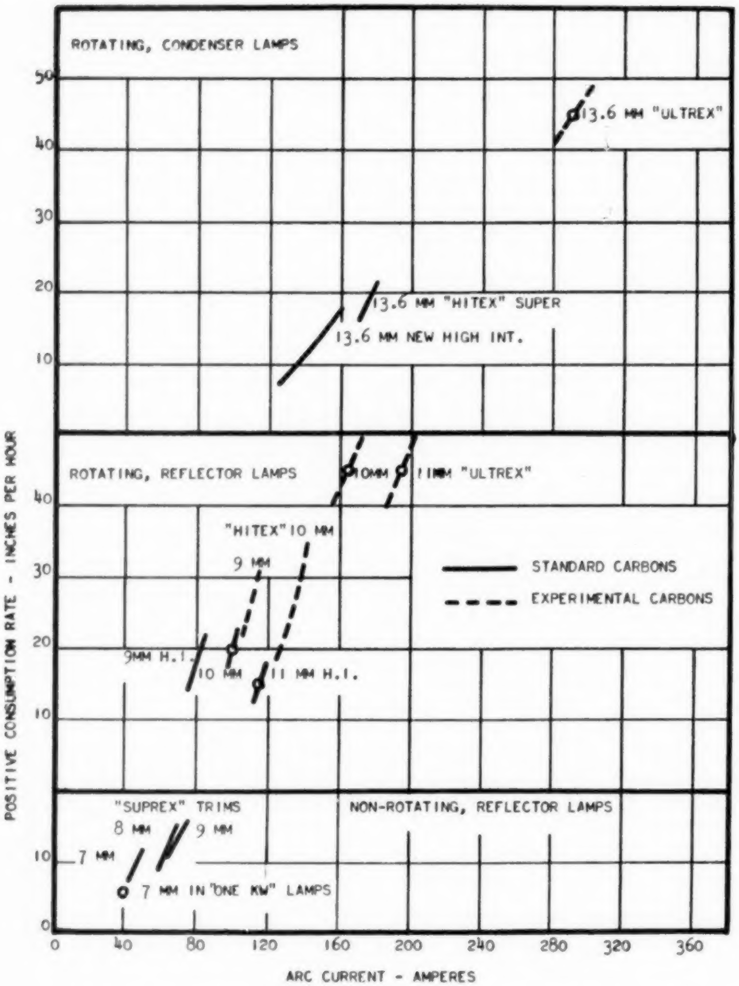

Fig. 4. Positive carbon consumption rate vs. arc current (see Table II).

approximately 5 ft and would make available recommended levels of brightness for screens fully 30 ft in width. Alternatively, the development of a suitable magazine-type lamp, designed for joining of carbons and continuous burning from one carbon to another, may be possible, permitting maximum currents and adequately long burning periods.

Wide-Picture Requirements

The data of this paper are all limited to projection from a standard 35mm motion-picture film aperture. Although these data are not directly applicable to

other film-aperture sizes and picture aspect ratios, rough estimates can be made in some instances. For example, the outputs of the various 35mm film-projection systems shown in Table II and Fig. 3 may be redistributed by optical means over various sizes and shapes of film apertures and projection screens. If this is accomplished with minor or known losses, then the data of Table II and Fig. 3 can be used to calculate approximately the results expected in such particular cases, assuming roughly the same lumen output available for redistribution.

The data of this paper can thus be applied to the requirements of CinemaScope, which employs a standard projection frame but an 8:3 picture aspect ratio, once the information is known on the transmission and reflection of the added accessories employed in this wide-picture process. For example, except for the optical losses in the added anamorphoscope lens which functions to produce a twofold expansion of picture width during projection, this expansion would produce a twofold increase in picture area and a 50% reduction in the available screen brightness obtainable with a normal unexpanded image. Therefore, the light requirements would be double those of conventional 35mm pictures on the same type of screen.

Directional-Type Projection Screens

Reference has been made in a number of instances to the effect of a directional screen. If suitable directional-type screens of higher reflection factor, with adequate uniformity over the audience area, can be obtained, these can reduce proportionately the lumen output required to illuminate a given size of screen to a specified brightness. For example, in the case of CinemaScope projection, discussed in the preceding paragraph, if a directional screen can be obtained with twice the reflection factor of a normal matte screen, then this should approximately compensate for the twofold increase in screen area produced by the anamorphoscope lens and permit approximate maintenance of the existing screen brightness with approximately the same projection lamp.

APPENDIX

The basic features of the lamps, optical systems and carbons employed in the tests to be described in this paper are shown in Table II. Whenever applicable, the same equipment was used and the same methods of measurements were employed as in the 1947 report.[1] All of the reflectors employed were second-surface silvered ellipsoidal ones of good quality. In every case the performance is typical of high-quality optical equipment, carefully adjusted and aligned, and light outputs are therefore in the upper range of what would generally be prevalent from the same equipment in motion-picture theaters. As noted in Table II, screen lumen values have been measured with no shutter, film or filters.

The flux of radiant energy through the center of the film aperture was measured with a portable-type aperture radiation meter[3] calibrated and checked in a few instances with the fundamental method described in this *Journal*.[4]

Burning rates will show some variation depending on the type and condition of the specific equipment in which the tests are made but the values shown in Table II are considered representative average figures.

Discussion of Data of Table II — Reflector-Type Lamps

The data on the "One Kilowatt" d-c trim remains unchanged from that previously reported.[1]

Items 2, 3 and 4 describe the performance of a new 7-mm Suprex positive carbon recently introduced to replace the former carbon in all except fixed-ratio "One Kilowatt" lamps. Items 5,

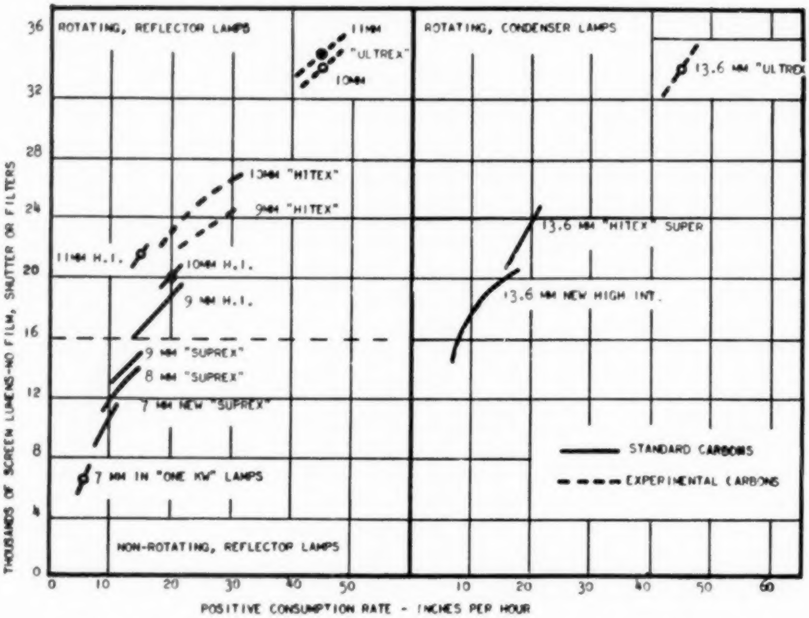

Fig. 5. Screen light vs. positive carbon consumption rate (see Table II).

6 and 7 are unchanged from the former data on the 8-mm Suprex trims.[1] Items 8 and 9 report data on a new 9-mm Suprex trim introduced about a year ago to produce a higher screen illumination and better distribution than the smaller size Suprex carbons.

Items 10 to 13 describe the performance of 9-, 10- and 11-mm rotating-type positive carbons commercially available for use in the newer rotating-type, high-speed reflector lamps at currents ranging from 75 to 115 amp.

Items 14 to 20 describe new experimental 9-mm and 10-mm Hitex carbons not yet commercially available. These are designed to operate at 105 to 135 amp to produce 25 to 35% more light than the standard 9- and 10-mm carbons. Due to higher power requirements at the higher currents and faster burning rates, lamps must be properly designed to accommodate these features.

Items 21 and 22 describe the expected performance of 10- and 11-mm Ultrex carbons designed to be operated with short positive carbon protrusion with water-cooled jaws to produce crater brightness as high as 1500 c/sq mm. As previously reported,[5-7] these positive carbons must be effectively cooled in order to realize the highest crater brightness. Due to the lack of any suitable commercial lamp designed to employ these carbons, their performance has been estimated from measurements made in an experimental lamp with an experimental reflector optical system as well as from calculations based on crater brightness measurements according to the methods described by Jones.[8,9] These Ultrex carbons make possible a further 30% increase in light beyond even the experimental Hitex carbon and an increase of 65% over the presently available 9-mm and 10-mm carbons.

Discussion of Table II — Rotating Condenser-Type Lamps

Items 23 to 25 describe the recently introduced 13.6-mm new high-intensity carbon, designed to equal, at the same current, the light of the former 125 to 150-amp carbon but with lower consumption and less heat at the aperture and able to operate at as high as 160 amp to produce 10% more light. Items 26 and 27 are the same data as previously reported[2] on the Hitex Super 13.6-mm carbon.

Items 28 and 29 describe the performance of a 13.6-mm Ultrex experimental carbon, designed like the 10-mm and 11-mm Ultrex carbons described above, for use with short protrusion in water-cooled jaws to produce very high crater brightness with condenser-type lamps. Results were reported on this type of carbon several years ago[5] in a study of its possibilities for motion-picture theater projection and motion-picture studio background projection. This trim makes it possible at 290 amp to project approximately 35% more light than from the 13.6-mm Hitex carbon at its maximum current.

Discussion of Screen Light

Figure 3 shows the data of Table II plotted as maximum screen lumens versus arc current. To eliminate confusion, the data on the condenser-type lamps have been plotted separately from those for reflector-type lamps. Reflector-type lamps produce lumen outputs below 15,000 lm as well as above. The condenser-type lamps and trims are generally confined to the production of lumen outputs above 15,000 lm. Both types are capable of projecting more than 20,000 lm with standard carbons and more than 30,000 lm with suitable experimental carbons. Sacrifice of some portion of the screen light may be necessary in some cases in order to reduce the radiant-energy flux at the film aperture to a tolerable level.

Discussion of Carbon Burning Rate

Figure 4 shows the positive carbon consumption rate data from Table II plotted versus the arc current. The data for the condenser lamps, for the rotating-type reflector lamps and for the nonrotating-type reflector lamps have each been plotted separately. Figure 4 is useful in determining maximum currents usable for various burning periods, such as 1-hr uninterrupted operation presently required for the projection of three-dimensional pictures.

Discussion of Screen Light in Relation to Positive Carbon Burning Rate

Figure 5 combines some of the data of Figs. 3 and 4 and plots the maximum screen light for each combination and operating current against the corresponding positive carbon consumption rate. Where the burning rates of different size carbons of the same type overlap, it is to be noted that the larger carbon always produces a greater amount of screen light for a given positive carbon consumption rate. This is important in connection with projection of three-dimensional pictures and any other application which sets a limit on the maximum usable consumption rate; for example, at 10 in./hr positive consumption rate, the 8-mm Suprex carbon produces approximately 10% more light and the 9-mm, approximately 20% more than the 7-mm Suprex carbon.

Discussion of Radiant-Energy Flux at Film Aperture

The data on radiant-energy flux at the film aperture as listed in Table II are not as complete as those for light and consumption rate. Also, these data must be used with some caution, particularly when comparing values between two different types of lamps and optical systems. Relative comparisons between different trims and currents employing a single lamp and optical system carry considerably more reliability than com-

Table II. Screen Illumination with Carbon-Arc 35mm Motion-Picture

Item	Carbons: Positive Type	Positive Catalog No.	Negative Type	Negative Catalog No.	Arc amp	Arc volts
Non-rotating, Reflector-Type Lamps — "One Kilowatt" d-c Trim						
1	7-mm × 12 or 14 in. Suprex	L0503 or L0506	6-mm × 9 in. Orotip C	L0563	40	27.5
Nonrotating High-Intensity Trims						
2	7-mm × 12 or 14 in. New Suprex	L0521 or L0525	6-mm × 9 in. Orotip C	L0563	42	36
3	7-mm × 12 or 14 in. New Suprex	L0521 or L0525	6-mm × 9 in. Orotip C	L0563	46	38
4	7-mm × 12 or 14 in. New Suprex	L0521 or L0525	6-mm × 9 in. Orotip C	L0563	50	40
5	8-mm × 12 or 14 in. Suprex	L0509 or L0512	7-mm × 9 in. Orotip C	L0566	60	36
6	8-mm × 12 or 14 in. Suprex	L0509 or L0512	7-mm × 9 in. Orotip C	L0566	65	38
7	8-mm × 12 or 14 in. Suprex	L0509 or L0512	7-mm × 9 in. Orotip C	L0566	70	40
8	9-mm × 14 in. Suprex	L0515	8-mm × 9 in. Orotip C	L0569	65	41
9	9-mm × 14 in. Suprex	L0515	8-mm × 9 in. Orotip C	L0569	75	45
Rotating, Reflector-Type Lamps						
10	9-mm × 20 in. High-Intensity	L0103	$\frac{5}{16}$ × 9 in. Orotip	L1106	75	52
11	9-mm × 20 in. High-Intensity	L0103	$\frac{5}{16}$ × 9 in. Orotip	L1106	85	58
12	10-mm × 20 in. High-Intensity	L0106	$\frac{11}{32}$ × 9 in. Orotip	L1115	100	60
13	11-mm × 20 in. High-Intensity	L0109	$\frac{3}{8}$ × 9 in. Orotip	L1124	115	55
14	9-mm × 20 in. Hitex	Exper.	$\frac{3}{8}$ × 9 in. Orotip	L1124	105	63
15	9-mm × 20 in. Hitex	Exper.	$\frac{3}{8}$ × 9 in. Orotip	L1124	110	65
16	9-mm × 20 in. Hitex	Exper.	$\frac{3}{8}$ × 9 in. Orotip	L1124	115	70
17	10-mm × 20 in. Hitex	Exper.	$\frac{7}{16}$ × 9 in. Orotip	L1130	125	64
18	10-mm × 20 in. Hitex	Exper.	$\frac{7}{16}$ × 9 in. Orotip	L1130	130	66
19	10-mm × 20 in. Hitex	Exper.	$\frac{1}{2}$ × 9 in. Orotip	L1139	135	70
20	10-mm × 20 in. Hitex	Exper.	$\frac{1}{2}$ × 9 in. Orotip	L1139	140	75
21	10-mm Ultrex[6]	Exper.	Exper.		165	80
22	11-mm Ultrex[6]	Exper.	Exper.		195	80

Film Projection Systems — 0.600 in. × 0.825 in. Aperture.

Lamp optical sys.	Radiant-energy flux at center of film aperture[4]	80% dist.		Max. light[3]		Approx. carbon consump. rate, in./hr	
	w/sq mm	Screen lumens[1]	% dist.[2]	Screen lumens[1]	% dist.	Pos.	Neg.
11¾ in. dia $f/2.5$ mirror		5,900	80	6,500	65	5.8	3.4
14 in. dia $f/2.3$ mirror		7,250	80	8,650	60	7.6	3.8
14 in. dia $f/2.3$ mirror		8,150	80	10,000	60	9.3	4.0
14 in. dia $f/2.3$ mirror	.55	9,200	80	11,700	60	11.6	4.3
14 in. dia $f/2.3$ mirror		10,300	80	11,000	65	9.0	3.8
14 in. dia $f/2.3$ mirror		11,800	80	12,700	65	11.8	4.0
14 in. dia $f/2.3$ mirror	.65	13,000	80	14,000	65	15.0	4.3
14 in. dia $f/2.3$ mirror		12,300	80	13,000	70	10.5	3.3
14 in. dia $f/2.3$ mirror	.70	13,800	80	15,000	70	15.5	3.8
16–16½ in. dia $f/1.9$ mirror		13,000	80	16,000	60	14.0	3.3
16–16½ in. dia $f/1.9$ mirror	.88[5]	15,000	80	19,500	55	22.0	3.5
16–16½ in. dia $f/1.9$ mirror	.88[5]	16,000	80	20,000	60	20.0	3.0
16–16½ in. dia $f/1.9$ mirror	.90[5]	18,500	80	21,500	65	15.0	2.5
16–16½ in. dia $f/1.9$ mirror	.89[5]	(16,500)	80	22,000	60	21.5	2.0
16–16½ in. dia $f/1.9$ mirror	.95[5]			23,500	60	27.5	2.3
16–16½ in. dia $f/1.9$ mirror	1.03[5]	(19,500)	80	24,500	60	31	2.5
16–16½ in. dia $f/1.9$ mirror	.95[5]			24,000	65	19.5	2.4
16–16½ in. dia $f/1.9$ mirror	1.00[5]	(21,000)	80	25,500	65	25	2.6
16–16½ in. dia $f/1.9$ mirror	1.05[5]			26,500	65	32	1.7
16–16½ in. dia $f/1.9$ mirror	1.06[5]	(22,000)	80	27,000	65	38	1.8
Exper. $f/2.0$ mirror	(1.3)[5]			(34,000)	(60)	45	
Exper. $f/2.0$ mirror	(1.3)[5]	(28,000)	80	(35,000)	(65)	45	

See conclusion of table and notes on following pages.

Table II

Item	Carbons: Positive Type	Positive Catalog No.	Negative Type	Negative Catalog No.	Arc amp.	Arc volts
Rotating, Condenser-Type Lamps						
23	13.6-mm × 22 in. New High-Intensity	L0115	$\frac{7}{16}$ × 9 in. Orotip	L1130	125	68
24	13.6-mm × 22 in. New High-Intensity	L0115	$\frac{1}{2}$ × 9 in. Orotip	L1139	150	74
25	13.6-mm × 22 in. New High-Intensity	L0115	$\frac{1}{2}$ × 9 in. Orotip	L1139	160	77
26	13.6-mm × 22 in. Hitex Super	L0175	$\frac{1}{2}$ × 9 in. Orotip Heavy Duty	L1142	170	70
27	13.6-mm × 22 in. Hitex Super	L0175	$\frac{1}{2}$ × 9 in. Orotip Heavy Duty	L1142	180	74
28	13.6-mm × 22 in. Ultrex[6]	Exper.	Exper.		265	
29	13.6-mm × 22 in. Ultrex[6]	Exper.	Exper.		290	80

Note: Values in parentheses are estimated or obtained from limited measurements.

[1] Screen lumen figure is for systems with no shutter, film or filters of any kind; measured with 5-in. E.F. $f/2.0$ and $f/1.9$ projection lenses.

[2] % distribution refers to ratio of light intensity at side of screen to that at the center.

[3] Maximum light is value with system adjusted to produce maximum light intensity at the center of the screen.

[4] Radiant-energy flux at the center of the film aperture with the system adjusted to produce maximum intensity at the center.

[5] Radiant-energy flux higher than 0.80 w/sq mm may require the use of a heat filter and/or other means to protect the film from the effects of the radiation — may result in some loss of light.

[6] Experimental carbons burned with short protrusion in experimental water-cooled silver jaws.

Concl'd.

Lamp optical sys.	Radiant-energy flux at center of film aperture[4] w/sq mm	80% dist. Screen lumens[1]	80% dist. % dist.[2]	Max. light Screen lumens[1]	Max. light % dist.	Approx. carbon consump. rate, in./hr Pos.	Approx. carbon consump. rate, in./hr Neg.
Condenser lenses at f/2.0	.64	11,500	80	14,500	60	7.25	2.4
Condenser lenses at f/2.0	.90[5]	16,000	80	19,500	60	14.0	1.9
Condenser lenses at f/2.0	1.00[5]	(16,500)	80	20,500	60	17.5	2.1
Condenser lenses at f/2.0	.97[5]	17,500	80	20,700	60	16.0	2.3
Condenser lenses at f/2.0	1.10[5]	19,300	80	24,800	60	21.5	2.5
Condenser lenses at f/2.0		(26,000)	80	(28,000)	(60)		
Condenser lenses at f/2.0	1.50[5]	(30,000)	80	(34,000)	(60)	45	

parisons between different lamps and optical systems, where the radiant-energy flux values can be significantly affected by differences in the nature of the reflective surface of reflectors and of the transmission properties of condenser systems.

The spectral reflection and transmission characteristics of the optical system over the entire spectrum determine the radiant-energy flux at the film aperture, but only those pertaining to the visible portion of the spectrum influence the amount of projected light. The behaviors of different optical materials are often proportionately different in their effect on heat and light. Also, many of the factors which can influence the amount of light projected can influence the radiant-energy flux at the aperture differently with one projection system than another. Relative comparisons with a single lamp and optical system are generally free from such effects. However, subject to the same restrictions and qualifications appropriate to the data on the amount of projected light,[1] it is believed that the heat-at-the-film values are correspondingly typical for the specific equipment employed.

The radiant-energy flux values of Table II have been plotted in Fig. 6 against the corresponding arc current.

For a specification of the critical level of radiant-energy flux, reference is made to the thorough study of black-and-white positive release print film made by Kolb,[10] who reported that "in-and-out of focus occasionally may be observed at projection intensities of 0.40 mean net watt per square millimeter; and that, beyond an intensity of 0.50 mean net watt per square millimeter, in-and-out of focus is almost certain to occur within the first five to ten days of projection in the theater." Since Kolb's values of mean net flux are determined with the shutter running, assuming a 50% shutter, these will correspond to twice as much flux on the scale of Table II and Fig. 6 which were measured without shutter. This

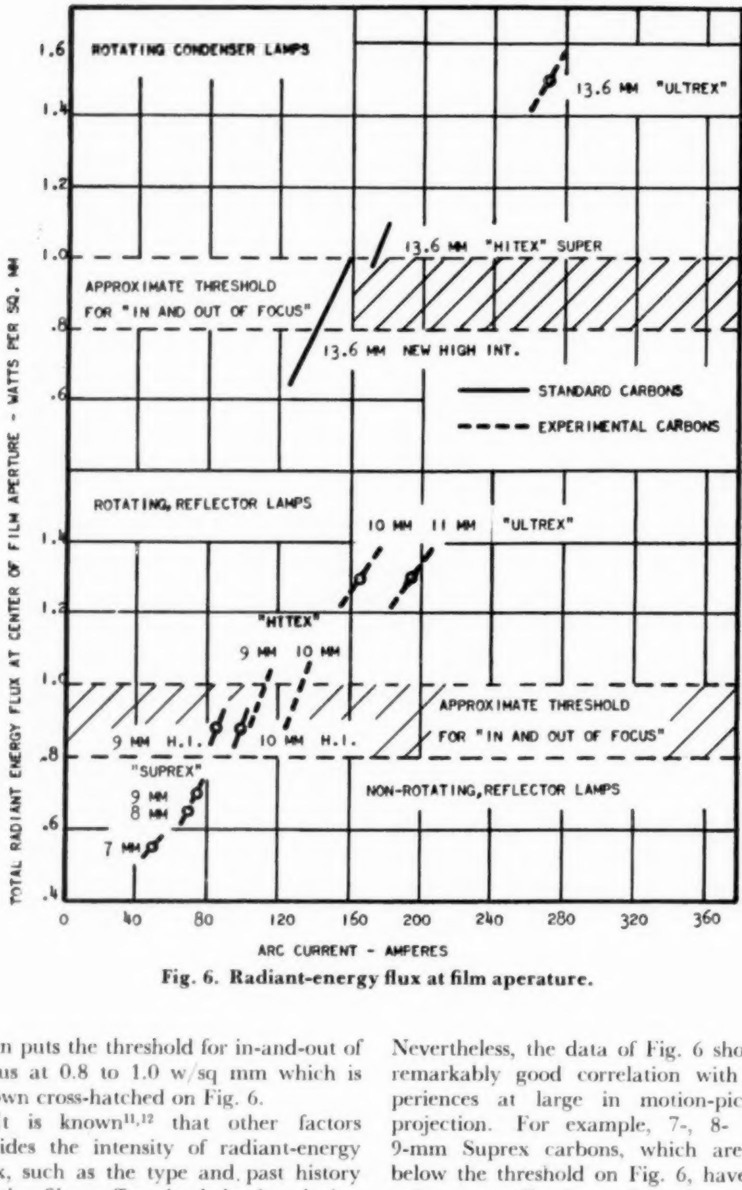

Fig. 6. Radiant-energy flux at film aperature.

then puts the threshold for in-and-out of focus at 0.8 to 1.0 w/sq mm which is shown cross-hatched on Fig. 6.

It is known[11,12] that other factors besides the intensity of radiant-energy flux, such as the type and past history of the film, affect its behavior during projection and have an influence on the appearance or nonappearance of undesirable effects of the heat-on-film. Nevertheless, the data of Fig. 6 show a remarkably good correlation with experiences at large in motion-picture projection. For example, 7-, 8- and 9-mm Suprex carbons, which are all below the threshold on Fig. 6, have all quite generally been free from any heat-on-film problems. The 9- and 10-mm high-intensity carbons employed in the rotating-type reflector

lamp have in some cases experienced difficulty and in others been free from it.

Passing over to the condenser-type lamp, the 13.6-mm high-intensity carbons employed in the condenser-type lamps have been free from heat-on-film problems only in the lower part of the current range. It has also been quite generally recognized that this trim at the upper part of its current range and also the 13.6-mm Hitex super high-intensity carbon must make some provision to protect the film from the effects of radiant energy. So much then for the facts obtained from past motion-picture experience, as well as from the direct tests of Kolb on this subject. From all this, it is definitely indicated that 9- and 10-mm Hitex carbons and the 11-mm Ultrex carbon in rotating reflector lamps, as well as the 13.6-mm Hitex super carbon and the 13.6-mm Ultrex carbon in condenser-type lamps, will project more radiant-energy flux through the aperture than can be accommodated by black-and-white film unless preventive and corrective measures are taken.

It is not the purpose of this paper to specify means of protection of the film from high levels of radiant-energy flux. It will be pointed out however, that the use of infrared absorbing filters, infrared reflecting filters, controlled air blast and the use of a water-cooled film gate have all been claimed to provide some protection to the film.[10,11,13] Infrared absorbing filters can remove 40% to 50% of the total radiant energy at the film aperture with an accompanying loss of 20% to 25% of the visible light.[4] Some infrared reflecting filters can reduce the total energy at the aperture 30% to 40% with not more than 10% loss of visible light. Kolb concluded[10] that suitable "air-cooling" of the film might permit increases of 30% to 60% in the safe maximum light intensity. Multiple usage of more than one of these protective measures may be necessary to accommodate the 1.3 to 1.5 w/sq mm levels of such extremely bright sources as Ultrex carbons.

It should be emphasized that this threshold value for in-and-out of focus discussed above and shown in Fig. 6 refers to typical black-and-white release-print film. It is generally recognized that dye-image color films, because of transparency to infrared radiation, are less subject to the effects of radiant-energy flux than black-and-white film.

It should also be recognized that light losses due to inefficient or badly adjusted optical-system components or other elements of the projection system, which reduce the light level below the maximum values shown in Table II, will often also reduce the radiant-energy flux values below those quoted and will sometimes render safe an otherwise damaging light source. This is doubtless a partial explanation for reported instances of freedom from film damage with trims and currents, which might be indicated from Table I and Fig. 6 to be above the threshold level for trouble.

Necessity of Suitable Lamp and Projector Design

Proper design of lamps and projectors is essential to the successful utilization of experimental carbons such as the experimental Hitex and Ultrex carbons described in this paper. This means suitable provisions must be made to accommodate the higher power requirements, the faster burning rates and the high level of light and heat output. Close control of arc position,[14] desirable under all conditions, becomes essential with very rapid burning rates. The air-blown type of arc, described in this *Journal* in 1950,[15] may have important advantages in arc control and performance. Many of the carbons described in this paper can be used with this type of operation.

Note: The terms Suprex, Orotip, Hitex, Ultrex and National are trade-marks of National Carbon Company, a Division of Union Carbide and Carbon Corporation.

References

1. R. J. Zavesky, C. J. Gertiser and W. W. Lozier, "Screen illumination with carbon arc motion picture projection systems," *Jour. SMPE, 48:* 73–81, Jan. 1947.
2. R. M. Bushong and W. W. Lozier, "New 13.6-mm. Hitex super high-intensity carbon," *Jour. SMPTE, 54:* 725–731, June 1950.
3. A. J. Hatch, Jr., "Portable device for measuring radiant energy at the projecture aperture," *Jour. SMPE, 53:* 363–367, Oct. 1949.
4. R. J Zavesky, M. R. Null and W. W. Lozier, "Study of radiant energy at motion picture film aperture," *Jour. SMPE, 45:* 102–108, Aug. 1945.
5. M. T. Jones, R. J. Zavesky and W. W. Lozier, "A new carbon for increased light in studio and theater projection," *Jour. SMPE, 45:* 449–458, Dec. 1945.
6. M. T. Jones and F. T. Bowditch, "Optimum performance of high-brightness carbon arcs," *Jour. SMPE, 52:* 395–406, Apr. 1949.
7. Wolfgang Finkelnburg, "Effect of carbon cooling on high-current arcs," *Jour. SMPE, 52:* 407–416, Apr. 1949.
8. M. T. Jones, "Motion picture screen light as a function of carbon-arc-crater brightness distribution," *Jour. SMPE, 49:* 218–240, Sept. 1947.
9. M. T. Jones and F. T. Bowditch, "Carbon arc characteristics that determine motion picture screen light," *Jour. SMPTE, 56:* 310–316, Mar. 1951.
10. F. J. Kolb, Jr., "Air cooling of motion picture film for higher screen illumination," *Jour. SMPE, 53:* 635–664, Dec. 1949 (see p. 648).
11. E. K. Carver, R. H. Talbot and H. A. Loomis, "Effect of high-intensity arcs upon 35-mm film projection," *Jour. SMPE, 41:* 69–87, July 1943.
12. E. K. Carver, R. H. Talbot and H. A. Loomis, "Film distortions and their effect upon projection quality," *Jour. SMPE, 41:* 88–93, July 1943.
13. Willy Borberg, "Modulated air blast for reducing film buckle," *Jour. SMPTE, 59:* 94–100, Aug. 1952.
14. D. J. Zaffarano, W. W. Lozier and D. B. Joy, "Improved methods of controlling carbon arc position," *Jour. SMPE, 37:* 485–501, Nov. 1941.
15. Edgar Gretener, "Physical principles, design and performance of the Ventarc high-intensity projection lamps," *Jour. SMPTE, 55:* 391–413, Oct. 1950.

Picture Quality of Motion Pictures as a Function of Screen Luminance

By LAWRENCE D. CLARK

The relationship between the quality of projected motion-picture prints and screen luminance has been investigated. Optimum prints for each of four levels of screen luminance from 2.8 to 81 ft-L were selected from a group of prints varying in density and contrast. The relative quality of the optimum prints evaluated subjectively was found to increase with screen luminance until the luminance reached approximately 25 ft-L, and then to decrease at the higher screen luminance levels. A range of screen luminances from about 10 to 45 ft-L gave picture quality that was within 10% of the best obtained. These results apply when there is no ambient illumination in the projection room other than that resulting from projector lens flare and light scattered from the screen.

With the introduction of high-current carbons which made possible the projection of motion pictures at higher screen luminances than could previously be realized, it was considered desirable to investigate the effect of these higher screen luminances on the characteristics required for optimum prints and on the quality of the projected motion pictures. There were three specific questions which should be answered by such an investigation:

(1) Is there a difference in the density and contrast of prints which give optimum quality at various screen luminances?

(2) Provided the optimum print is made for each screen luminance, is there a difference in the relative quality of the projected pictures when these prints are shown at the screen luminances for which each is optimum?

(3) To what extent is the quality of the projected picture affected by the screen luminance when the same print is shown at various screen luminances? (It is assumed that the print has been selected as optimum for one of the screen luminances at which it is shown.)

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(This paper was received April 11, 1953.)

Plan of the Experiment

To obtain information which would provide reliable answers to these three questions, the following plan was adopted for the experiments:

The Negatives: Four negatives were

obtained which are typical of those made in normal motion-picture practice with respect to the type of scenes, the negative materials and the production techniques.

The Prints: Prints were made on Eastman Fine Grain Release Positive Safety Film from each of the negatives, the printing exposure and the degree of development being varied over a wide range.

Selection of Optimum Prints: All the prints were projected at each of several different screen luminances, from the lowest to the highest luminance which may be of interest in practice. A group of observers then selected the print which was considered best at each screen luminance.

Picture-Quality Evaluation: (1) Each of the prints which was selected as optimum was projected in sequence at the screen luminance for which each was optimum. A group of observers compared the projected pictures and assessed the relative quality of each.

(2) *All* the selected optimum prints of each scene were projected at one screen luminance. The observers were asked to assess the relative quality of the projected pictures in this case. This procedure was repeated at the various screen luminances.

Experimental Procedure

In accordance with the plan just outlined, 35-ft lengths of negatives were obtained for each of four types of scenes: (1) a close-up — studio lighting; (2) a medium-length view — outdoor lighting; (3) a low-key night scene — studio lighting; (4) a high-key scene — outdoor lighting. The first three of these scenes were taken from Hollywood productions, and the fourth was produced especially for this experiment. From each of these negatives prints were made on Eastman Fine Grain Release Positive Safety Film, developed to approximately the following values of gamma: $\gamma = 1.9$, 2.1, 2.3, 2.5 and 2.7. The printing exposure was varied so that at each value of gamma a series of prints was obtained varying from too light to too dark.

Each of these prints was shown to a group of observers in a projection room with a short projection distance, which permitted obtaining screen luminances above 80 ft-L. Four different screen luminances were selected to cover a range somewhat greater than is normally available in motion-picture theaters. The changes in screen luminances were produced by alterations in arc current and changes in the filter screen used in in the projector. The luminance was measured at the center of the screen with a Macbeth Illuminometer from a point near the projector axis. The average values of luminance for the four projector settings were 2.8, 10.5, 24.5 and 81.3 ft-L. The only light in the room was that reflected from the screen or scattered from the projector beam.

Three different showings were required to obtain the necessary picture-quality judgments.

First Showing: With the projector operating to produce a screen luminance of 2.8 ft-L, all the prints from each of the negatives were shown. The observers were asked to select the print which gave best quality for each of the scenes. When this judgment had been made, the same group of prints was shown again, but at a screen luminance of 10.5 ft-L. Again, the observers were asked to select the print which gave best quality for each of the scenes. This judgment was repeated with the pictures projected at screen luminances of 24.5 ft-L and 81.3 ft-L. The prints were judged one at a time, never in pairs, in order to keep the eye adaptation always appropriate to the particular pictures under consideration. This was considered necessary in spite of the greater difficulty in making successive rather than simultaneous quality judgments. Thus, an optimum print was

Table I. Characteristics of Optimum Prints Selected for Four Screen-Luminance Levels

Screen Luminance, ft-L	Characteristic of Print	Scene 1	Scene 2	Scene 3	Scene 4
2.8	Minimum density	0.24	0.17	0.07	0.16
	Maximum density	2.20	2.70	2.23	2.19
	γ of material	2.70	2.70	2.04	2.70
10.5	Minimum density	0.26	0.20	0.09	0.17
	Maximum density	2.30	2.77	2.35	2.23
	γ of material	2.70	2.50	2.04	2.70
24.5	Minimum density	0.31	0.20	0.10	0.20
	Maximum density	2.38	2.82	2.48	2.31
	γ of material	2.50	2.50	2.04	2.50
81.3	Minimum density	0.38	0.25	0.16	0.22
	Maximum density	2.51	3.02	2.81	2.35
	γ of material	2.50	2.50	2.04	2.50

determined for each of the four screen luminances for each of the scenes.

Second Showing: From the first showing, four prints were selected for each of the four scenes. Each of the four prints represented the optimum print for one of the four screen luminances. In the second showing, the observers were asked to rate the relative quality of the projected pictures when these four prints from each of the negatives were projected, each at the screen luminance for which it was chosen as optimum. These four prints from each negative were spliced together with sufficient leader between each pair of adjacent prints to allow time for changing the projector filter screens and arc current, without stopping the projector. The observers were asked to indicate the relative picture quality associated with the four prints from each negative by assigning quality numbers, arbitrarily using the number 10 to represent the best quality obtained. In this manner, the average relative quality obtained by projecting each of the four prints from each scene could be computed from the judgment data by standard statistical methods.

Third Showing: In the third showing, the four optimum prints from each negative were all projected at each of the four screen luminances. The observers were asked to assign relative quality numbers to the four projected pictures at each screen luminance. In this showing, each print was projected at the four screen luminances rather than at the one screen luminance for which it was considered optimum. By combining the results of the third showing with the results of the second showing, it was possible to determine, indirectly, the approximate quality associated with each print as a function of screen luminance.

Tone-Reproduction Evaluations

A complete description of the characteristics of the negatives and the positives was assembled in the form of objective tone-reproduction diagrams. Such a diagram is shown in Fig. 1, which applies to Scene 1. In the lower-right quadrant is the characteristic curve of the negative. Density is plotted as a function of the logarithm of relative scene luminance. This curve was obtained by assuming that an average amount of flare light reached the camera image, and by applying the necessary correction to a typical sensitometric curve of the negative material. In the lower-left quadrant,

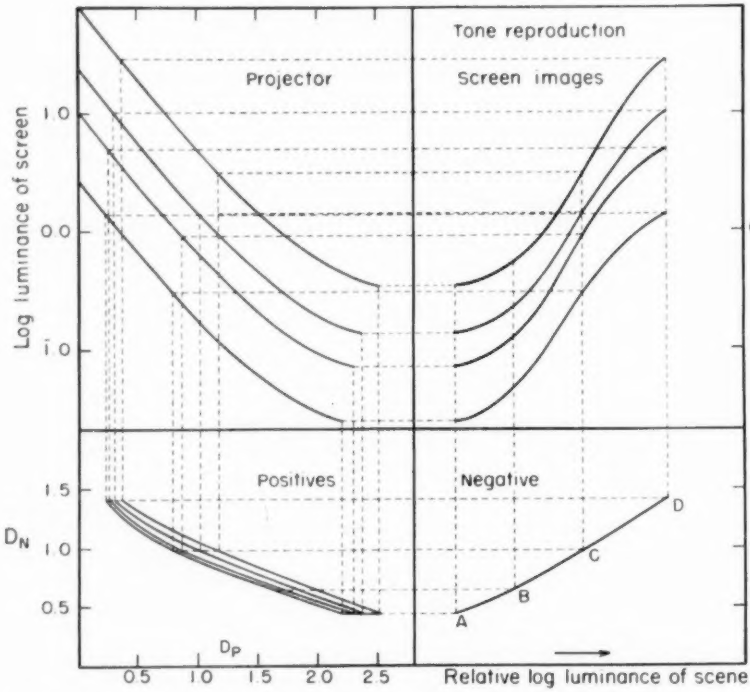

Fig. 1. Tone-reproduction diagram for Scene 1, showing comparison between the four optimum prints, each projected at the screen luminance for which it is optimum. Points A–D on the negative curve correspond to the luminance of different areas in the scene: A, extreme shadow; B, lower portion of background; C, background near face; and D, extreme highlight.

the characteristic curve of the positive material is shown in four different positions along the log-E axis representing the relationship between negative and positive in the four different prints from the same negative. In the upper-left quadrant, the projector characteristics are shown. In this quadrant, the logarithm of the luminance of the screen image is plotted as a function of print density. This curve takes into account the specularity of the projector and the influence of non-image-forming light which reaches the screen from the projector lens, room walls, etc. The intercepts of these curves on the screen-luminance axis indicate the logarithm of the screen luminance as measured with no film in the projector.

In the upper-right quadrant of Fig. 1, the log luminance of the projected image is plotted as a function of the logarithm of the luminance of the corresponding objects in the original scene.

The tone-reproduction curves provide a complete description of the characteristics of the projected pictures, including the characteristics of the positive prints. Since Fig. 1 applies only to Scene 1, some indication is needed of the characteristics of the positive prints which were selected as optimum for each of

the screen levels for all the scenes. In Table I are shown the minimum and maximum density values and the gammas to which the film was developed for the optimum prints made from each scene.

Results

Figure 2 presents a summary of the results of the picture-quality appraisals in the form of curves in which picture quality is plotted as a function of the logarithm of screen luminance for the case in which only the optimum prints are shown at each screen luminance. In Fig. 3 the results of comparing all four of the optimum prints at each screen luminance are shown. Each of the curves is based on the average of the judgments made for the four different scenes. Each curve indicates the change in quality with screen luminance only. The most important feature of these curves is in what they reveal about the range in screen luminance over which the various prints give top or near-top quality.

Conclusions

For the conditions used in these tests:

(1) There is evidence that, as screen luminance is increased, the density of the print must be increased, and the density scale lowered to maintain optimum quality.

(2) The present American Standard (PH22.39-1953) for theater screen luminance (10 ft-L +4, −1) gives picture quality which is definitely superior to that obtained with lower screen luminances.

(3) Increasing the screen luminance from 10 to approximately 25 ft-L will give some improvement in quality in most cases, provided the proper adjustment is made in the density and contrast of the print.

(4) Quality decreases when screen luminance is increased above approximately 25 ft-L.

(5) Quality within 10% of the best can be obtained over a wide range of screen-luminance levels, beginning at about 10 ft-L and extending to about 45 ft-L.

(6) The objective tone-reproduction curves for this experiment do not give a definite explanation for the quality decrease at higher screen luminances. Visual discomfort or other subjective effects due to viewing picture areas of high luminance in the presence of a dark surround may be more important factors.

(7) Further experiments are needed to determine the cause of the quality decrease and to measure quality as a function of screen luminance under varying conditions of ambient illumination and picture surround. Such experimentation should include still projection to determine whether flicker, which becomes apparent only at the higher screen-luminance levels, is a factor in lowering quality. An attempt should also be made to derive the subjective tone-reproduction curves.

(8) Prints which were made to give optimum quality at one screen luminance are generally inferior, when projected at higher or lower screen luminances, to other prints which are optimum for the higher or lower screen luminances (Fig. 3). It is not always possible in practice, however, to make different prints for projection at different screen luminances, and it becomes necessary to make a single print which will give the best average quality over a wide range of screen luminances. The data indicate that it is somewhat better to make prints which are optimum for a screen luminance of approximately 10 ft-L and show them at 2 ft-L than to make prints which are best for 2 ft-L and show them at 10 ft-L. Prints which give the best quality when projected at 10 ft-L will give somewhat higher quality throughout a wider range of screen luminance than the prints which are made to be optimum for the other screen luminance

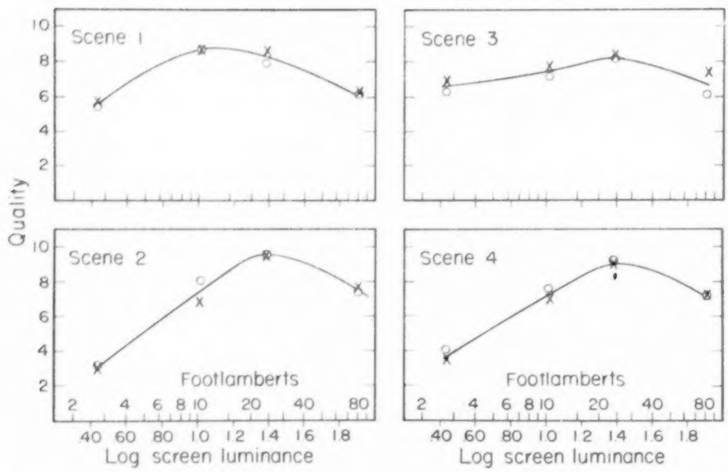

Fig. 2. Picture quality given by optimum prints shown as a function of screen luminance, each print projected at the screen luminance for which it was selected as optimum.

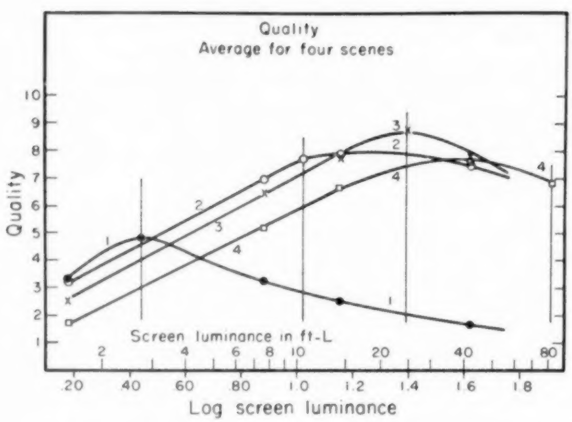

Fig. 3. Picture quality shown as a function of screen luminance for the case in which the same print is projected at various screen luminances. Vertical lines beginning at the left represent screen luminances for which prints 1, 2, 3 and 4, respectively, were chosen as optimum.

levels used in this test. This conclusion is particularly pertinent in view of the recent interest in a proposed standard for 16mm review-room screen luminance. Although these data are based on 35mm prints, it is felt that the results are indicative of what may be expected with 16mm prints also.

Acknowledgments

Thanks are due to the members of the staff of the Research Laboratories and to various members of other departments of Eastman Kodak Co. who assisted in gathering the data, making the prints and acting as judges. Acknowledgment is given particularly of the assistance given by J. H. Morrissey, of these Laboratories, in the mathematical treatment of the data.

Discussion

Max Pulejo (Fulbright Student, USC): You mentioned that the light and dark scenes were not shown simultaneously. What was the reason for this procedure, which involves a memory factor?

Dr. E. K. Carver (Eastman Kodak Co., Rochester, N. Y.): I think I can answer why they did not show the two simultaneously. If one does that, the bright one prevents seeing the dark one properly and would give a bias in favor of the bright one. It would be as if the eye adapted itself to the brighter one and made the less bright one seem dull. It is perfectly true that the memory factor gives more trouble when pictures are presented separately. This is partly compensated for if you have a fairly large number of observers. If you project both pictures together, it is probably easier to get agreement but the bias introduced would give you a wrong answer unless care is taken not to have two pictures on the screen at once that are very different in brightness.

Ben Schlanger (Architect, New York City): What was the distance of the observer in relation to the picture, and how wide was the picture?

Mr. T. G. Veal (Eastman Kodak Co., Rochester, N. Y.): The observer was approximately 27 to 28 ft and the picture width was about 8 to 10 ft.

Mr. Schlanger: With viewing distances in theaters being anywhere from 1 W up to about 6 W, I would imagine that a viewing distance of approximately 4½ W (W being width of the picture), would be a more valid test.

Mr. Veal: That is true. It is our intention to make such a test.

Mr. Schlanger: What was the nature of the lighting of the room and the nature of the lighting adjacent to the picture? Was there a black border around the picture and was the room kept dark or was there some ambient light in the room?

Mr. Veal: There was no border around the picture and there was no light in the room, excepting that coming from the lens, which gave an average ambient illumination of approximately 0.4 ft-L.

Mr. Schlanger: Getting away from the technical side and considering the psychological values, an observer wants to feel, when looking at a daylight scene, that it really feels like daylight and, of course, when you have a dark scene, it should impress you as a dark scene. Have any tests been made on this point?

Mr. Veal: It has been my experience, and I believe Dr. Lozier will agree, that when you have a bright sunlight scene, it will look more realistic when projected at a high screen luminance. We plan to do some tests to check this point.

Optimum Screen Brightness for Viewing 16mm Kodachrome Prints

By L. A. ARMBRUSTER and W. F. STOLLE

The Laboratory Practices Committee of this Society has completed a survey of viewing conditions in several 16mm print review rooms.[1] This survey has led to the proposal that a screen-brightness standard of 7.5 ± 2.5 ft-L be adopted as a laboratory standard. The Society's Non-Theatrical Equipment Committee in 1941 recommended as a standard for non-theatrical projections a screen brightness level of 10 ft-L with a range extending from 5 to 20 ft-L.[2] Production standards, tolerances and aimpoints used in the manufacture of Kodachrome Commercial and Kodachrome Duplicating Films are in some measure dependent upon the viewing conditions used. Viewing standards for the Eastman Kodak Co. are currently 14 ± 4 ft-L. The effects of screen brightness, camera exposure and print exposure upon the quality of prints made on 16mm Kodachrome Duplicating Film from 16mm Kodachrome Commercial Film originals have been studied. The optimum screen-brightness range was from 9 to 15 ft-L.

The Laboratory Practices Committee of the Society of Motion Picture and Television Engineers after a survey of viewing conditions in several East and West Coast 16mm print review rooms is proposing a screen-brightness standard of 7.5 ± 2.5 ft-L to the SMPTE Standards Committee for their action. Because this value is somewhat lower than the intra-company standard of 14 ± 4 ft-L in general use by the Eastman Kodak Co., this study was undertaken to determine the optimum screen-brightness level for viewing 16mm Kodachrome prints.

Presented on April 29, 1953, at the Society's Convention at Los Angeles by Allan M. Koerner for the authors, L. A. Armbruster and W. F. Stolle, Color Control Div., Eastman Kodak Co., Rochester 4, N.Y.
(This paper was received March 27, 1953.)

Procedure

The Kodachrome Commercial Film — Kodachrome Duplicating Film combination was used on this program because of widespread use of these materials. The resultant prints were judged over a range of screen-brightness levels. Related very closely to this problem is the matter of proper exposure level for the Kodachrome Commercial Film and the subsequent print density of the duplicates.

It is assumed that if a laboratory had a low screen brightness in its viewing

room, some effort might be made to adjust the original and print densities to give best results at the particular level used. Conversely, if a high screen brightness were used, an opposite adjustment might be made. Hence, there is a need for prints of different densities and contrasts in order to determine the effect of these prints on the choice of an optimum brightness level for viewing.

The original used was Kodachrome Commercial Film, Type 5268, which was exposed as recommended, i.e., for daylight, a film-exposure index of 8 with a Kodak Wratten Filter No. 83 and for 3200 K illumination a film-exposure index of 10.

Initially, twelve different scenes were photographed at daylight and interior conditions using the normal exposure, one-stop overexposure, and one-stop underexposure. The twelve scenes were critically viewed in order to select four, two daylight and two interior scenes, which most nearly matched the type and range of subjects encountered in the trade. The daylight pictures consisted of (1) a shoreline scene and (2) a scene showing a brick house, sky, trees and multicolored mail boxes. The two interior scenes consisted of (1) a rather high-key close-up portrait and (2) a commercial scene of a telephone-switchboard operator.

Prints were made on a Depue 16mm printer on Kodachrome Duplicating Film, Type 5265. The over and under camera exposures were timed with light control and neutral-density filters to provide prints of density level equivalent to those obtained from the normal camera exposures.

Having obtained a normal-print density for each camera-exposure level, the printing light was then varied from normal by the addition or subtraction of 0.15 neutral density. Thus there were available prints which were thin, normal and heavy at each of the three camera-exposure levels, to provide a selection of print densities for the various screen-brightness levels and to determine if the normal print density level is optimum.

The projection equipment consisted of two Eastman Model 25 Projectors with 1000-w projection lamps. The lenses were 3-in., $f/1.5$ projection Ektar lenses providing a screen-image diagonal of 4.3 ft with average viewing being encountered at 4.4 image diagonals from the screen. The screen was a white-painted, unperforated screen with a nonselective, diffuse surface having a reflectance of 91%.

Six screen-brightness variations were studied, 2, 5, 7.5, 10, 14 and 20 ft-L. The changes in illumination were accomplished by means of different-sized diaphragm apertures placed over the projection lens, and measurements were made at the center of the screen by means of a Luckiesh-Taylor Brightness Meter, manufactured by the General Electric Company.

Stray screen illumination is known to affect adversely the quality of the projected image. Table I shows the fraction of total screen brightness attributable to room lighting, lens flare, etc., at each screen-brightness level used.

Table I. Screen Brightness From Stray Light

Total Screen brightness level, ft-L	Stray brightness level, ft-L	% of total
2	0.015	0.75
5	0.019	0.38
7.5	0.022	0.29
10	0.024	0.24
14	0.028	0.20
20	0.029	0.15

The method of judgment used was the paired-comparison technique, i.e., the selection of the better of two simultaneously projected images. The various scene, camera-exposure, and print-density comparisons were shown in

Table II. Series I Comparison Pattern for Selection of Best Print at Each of Six Screen Brightnesses

	Group I	Group II	Group III
	OA vs. OB	NA vs. NB	UA vs. UB
Scene I	OA vs. OC	NA vs. NC	UA vs. UC
	OB vs. OC	NB vs. NC	UB vs. UC
Scene II, Scene III, Scene IV	Same comparisons made as for Scene I.		

Camera exposure	*Print density*
O = 1 stop overexposed	A—Printed light (normal −0.15 log E)
N = Normally exposed	B—Printed normal
U = 1 stop underexposed	C—Printed dark (normal +0.15 log E)

random order. Twelve to fifteen judges were used for each of the several viewings, with the majority, in general, having a considerable amount of experience viewing duplicate prints.

The first series of viewings was for the selection of the best of the three print-density levels for a given camera exposure. Six viewings were made in this series, each at a different screen-brightness level. Table II shows the pattern of comparisons for this series. The results of these projections gave an optimum print density for each of the three camera exposures for each of the screen-brightness levels.

The second series of viewings consisted of the selection of the best camera exposure for each of the screen-brightness levels using the best print density for each camera exposure selected in the Series I viewings. Six projections

Table III. Series II Comparison Pattern for Selection of Best Camera Exposure Screen Brightness in Footlamberts

	2	5	7.5	10	14	20
	OA vs. NA	OB vs. NA	OB vs. NA	OB vs. NB	OB vs. NB	OB vs. NB
Scene I	OA vs. UA	OB vs. UA	OB vs. UA	OB vs. UA	OB vs. UA	OB vs. UB
	NA vs. UA	NA vs. UA	NA vs. UA	NB vs. UA	NB vs. UA	NB vs. UB
	OB vs. NA	OB vs. NB	OB vs. NB	OB vs. NB	OB vs. NB	OC vs. NB
Scene II	OB vs. UB	OB vs. UB	OB vs. UB	OB vs. UB	OB vs. UB	OC vs. UC
	NA vs. UB	NB vs. UB	NB vs. UB	NB vs. UB	NB vs. UB	NB vs. UC
	OB vs. NB	OB vs. NB	OB vs. NB	OB vs. NB	OB vs. NB	OB vs. NB
Scene III	OB vs. UB	OB vs. UB	OB vs. UB	OB vs. UB	OB vs. UB	OB vs. UB
	NB vs. UB	NB vs. UB	NB vs. UB	NB vs. UB	NB vs. UB	NB vs. UB
	OB vs. NB	OB vs. NB	OB vs. NB	OC vs. NC	OC vs. NC	OC vs. NC
Scene IV	OB vs. UB	OB vs. UB	OB vs. UB	OC vs. UB	OC vs. UC	OC vs. UC
	NB vs. UB	NB vs. UB	NB vs. UB	NC vs. UB	NC vs. UC	NC vs. UC

Prints used are those selected in the Series I viewings.

Camera exposure	*Print density*
O = 1 stop overexposed	A—Printed light (normal −0.15 log E)
N = Normally exposed	B—Printed normal
U = 1 stop underexposed	C—Printed dark (normal +0.15 log E)

Table IV. Series III Comparison Pattern for Selection of Best Screen Brightness

Screen-brightness comparison, ft-L	Scene I	Scene II	Scene III	Scene IV
2 vs. 5	NA vs. NA	UB vs. UB	UB vs. NB	UB vs. UB
5 vs. 7.5	NA vs. NA	UB vs. UB	NB vs. NB	UB vs. UB
7.5 vs. 10	NA vs. NB	UB vs. UB	NB vs. NB	UB vs. NC
10 vs. 14	NB vs. NB	UB vs. UB	NB vs. NB	NC vs. NC
14 vs. 20	NB vs. NB	UB vs. NB	NB vs. NB	NC vs. OC

Prints used are those selected in series II viewings.

Camera exposure	*Print density*
O = 1 stop overexposed	A—Printed light (normal −0.15 log E)
N = Normally exposed	B—Printed normal
U = 1 stop underexposed	C—Printed dark (normal +0.15 log E)

Table V. Maximum and Minimum Densities of Normal Print from Normal Camera Record

	Scene I	Scene II	Scene III	Scene IV
D max	2.17	2.12	1.40	2.12
D min	0.68	0.52	0.37	0.55
Range	1.49	1.60	1.03	1.57

were also made in this series, each at a different brightness level. The results of these selections gave the optimum print-density — camera-exposure combination for each level of screen brightness. Table III shows the print comparisons used for Series II for all the respective levels.

The third and final viewing compared the various screen-brightness levels using the print-density — camera-exposure combination selected for each screen brightness in the Series II viewings. Table IV shows the prints used in this Series III study. Because of the psychological difficulties involved when judging two pictures of widely different brightnesses, only the minor brightness-increment comparisons were used, i.e., 2 vs. 5 ft-L, 5 vs. 7.5 ft-L, etc., to keep the brightness-level differences at a minimum. Table V shows the maximum and minimum densities of the normal prints made from the normal camera records for the four scenes.

Discussion of Results

The results of the Series I viewings are shown in Fig. 1 and indicate for each camera exposure the average percent acceptance of the three print-density levels for each level of screen brightness. This chart is a summation of the acceptances accredited to all four scenes for each print level. Table III, which shows the comparisons used for the Series II viewings, is made up of all prints selected in Series I projections. As one would expect, a low level of screen brightness tends to shift preference towards a thinner print as is evident in Table III, for the 2-ft-L level. Although the normal print on the average is most acceptable, Scene I and II selections are comprised of some thin prints. Conversely, at high levels the preference is shifted towards heavier prints as is noted for the 20-ft-L level in Table III. Here, again, although the general preference is for the normal print, some heavy prints were selected as optimum. Figure 1, except for the extreme screen brightness levels, indicates the density of the normal print is very satisfactory.

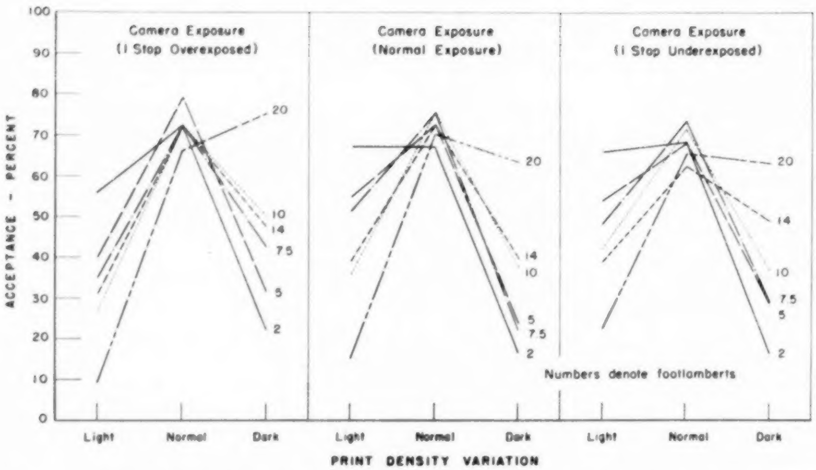

Fig. 1. Percent acceptance at six screen brightnesses for light, normal and dark Kodachrome duplicates from underexposed, normal and over exposed originals.

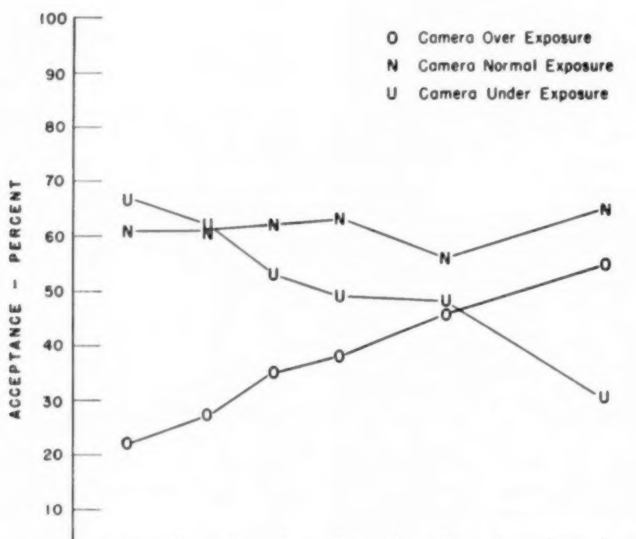

Fig. 2. Percent acceptance of best duplicate from underexposed, normal and overexposed originals at six screen brightnesses.

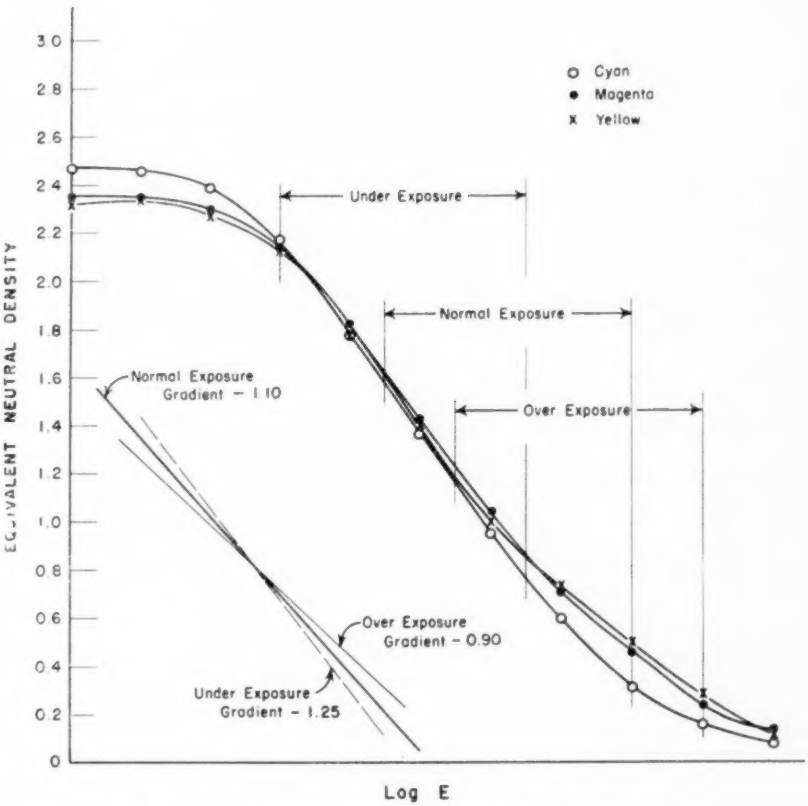

Fig. 3. Effect of exposure on gradient of typical Kodachrome Commercial Film, Type 5268.

The results of the Series II judgments for selection of the best camera exposure at the various levels is shown in Fig. 2 as a summation of acceptances for the four scenes. The normally exposed original maintained an even acceptance distribution throughout the brightness ranges while the preference at low levels is shifted toward the underexposed original, and at high levels the preference is shifted toward the overexposed original. The relationship of picture gradient to screen-brightness level is indicated in this study, the overexposed original being of lower gradient than the normal exposure and the underexposed original being of higher gradient. This is shown graphically on Fig. 3 where the density levels between two subjects influencing contrast are shown on a sensitometric curve for the different exposure levels. Consequently, at a low screen brightness, there is a desire to select a print of higher contrast obtained with an underexposed original and timed to give a print that is normal to slightly thin. Table IV shows that, at the 2-ft-L level, three of the four scenes selected were underexposed originals printed as normal, and the remaining scene was printed then from a

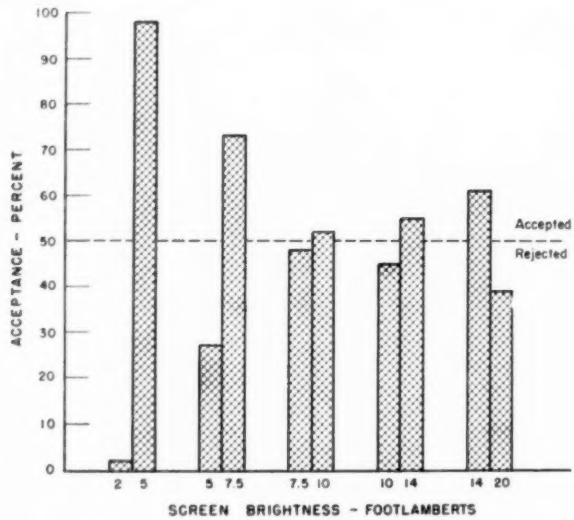

Fig. 4. Comparison of percent acceptance at each screen brightness with acceptance at next higher level; each pair = 100%.

normally exposed original. The converse trend is noted in Fig. 2 where at the high screen-brightness level the low-gradient, overexposed original was preferred to the higher-gradient, underexposed original. The final selections at the 20-ft-L level comprised three normal prints of normally exposed originals and one heavy print of an overexposed original (Table IV).

The results of the Series III viewings are shown on Fig. 4. This viewing determined the optimum screen brightness by comparing the four selected prints at 2 ft-L with the selected prints at 5 ft-L, etc. The data indicate that the decisions between 7.5 and 10 ft-L are about equally divided. Note that in this comparison any score under 50% is poor since it indicates that the other brightness was preferred. Since acceptance of the lower brightness drops sharply from 7.5- to the 5- and 2-ft-L level, the 7.5-ft-L level is considered the minimum acceptable level. The 14- vs. 20-ft-L comparison shows a definite preference for the 14-ft-L level. Thus the upper limit is considered to be in the range between 14 and 20 ft-L.

Additional testing by means of the single stimulus method (a single image projected at a given screen-brightness level) was undertaken to verify the results obtained by the paired-comparison technique. The illumination was varied from the low to the high levels and then repeated from the high to the low levels in the minor-increment differences. This system was used to reduce the effect of adaptation as much as possible. For this projection, the prints selected as optimum for each level of screen brightness were used and projected at their respective level. Fifteen experienced observers were asked to rate each scene at each brightness level, using a range of 1 to 5. The value 1 on the scale indicated an undesirable print — screen-brightness combination with value 5 being the most acceptable. Values 2, 3 and 4 were used for intermediate acceptance levels. The acceptance rating at

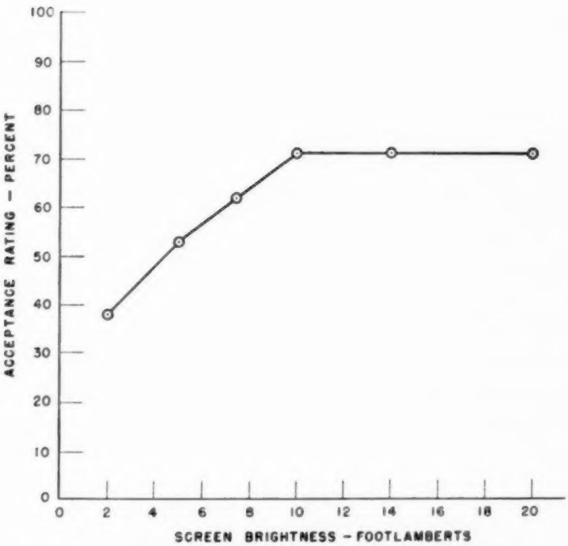

Fig. 5. Percent acceptance of prints at six screen brightnesses. Viewed singly with no comparison.

each brightness level is shown on Fig. 5. The single stimulus method generally confirmed the results obtained by the paired-comparison method, although it was thought to be considerably less critical because of the necessary reliance on memory of the appearance of the other scenes. Figure 5 does show, however, that acceptance for 7.5 ft-L is definitely less than for the higher values.

These data indicate, as shown by Figs. 4 and 5, that a value between 7.5 and 10 should be considered the lower limit and that the upper limit lies between 14 and 20 ft-L. The variation encountered in the measurement of screen brightness including instrument error, calibration and differences among observers is estimated to be $\pm 10\%$ of the value being measured. In view of these measurement errors a conservative brightness range for the viewing of 16mm Kodachrome prints is estimated to be 9 to 15 ft-L with 12 ft-L as the median value. These data show that screen-brightness levels below 7.5 ft-L are not desirable for viewing of 16mm Kodachrome prints.

More data at smaller increments of screen brightnesses must be obtained if the range limits are to be more closely defined.

Conclusions

The screen-brightness range which in the opinion of the majority of judges gave the most desirable 16mm Kodachrome prints was 9 to 15 ft-L with a median value of 12 ft-L. This selection was reached by means of the paired-comparison and the single-stimulus techniques.

For the related problems of exposure level for the Kodachrome Commercial Film and the print-density level of the duplicates definite conclusions may also be reached. The present exposure index of 10 for tungsten and 8 for daylight for the Kodachrome Commercial Film is correct. This is shown on Fig. 2 where for all screen-brightness levels except the extreme low values of 2 and 5

ft-L the normal camera exposure on the average was selected in preference to the over- and underexposures. The print density levels assumed to be normal were proved optimum inasmuch as the normal prints were selected on the average in preference to the thinner or heavier prints. The one scene for which the heavier print was selected was a scene having a fairly dark switchboard cabinet and high level of exposure for the operator. Although the average exposure for both subjects was correct, there was a tendency to desire more detail in the operator, obtained with a heavier print, with the cabinet reproduced somewhat darker.

References

1. Unpublished report on "Screen brightness survey of laboratory review rooms," SMPTE Laboratory Practice Committee, March 21, 1952. Appended to Committee Report No. 278 L.P. 6.3.
2. "Recommended procedure and equipment specifications for educational 16mm projection—A Report of the Committee on Non-Theatrical Equipment," *Jour. SMPE, 37:* 22–75, July 1941.

Discussion

Philip M. Cowett (Bureau of Ships): Would you say that the studies which you have made and the recommendations of 9 to 14 ft-L would also apply had your studies been made with black-and-white and with Technicolor film, or is this just one particular study on one particular film?

Mr. Koerner (who read the paper): I would not like to apply these results directly to any other films than the ones which we used here. On the other hand, I would be very much surprised if the results were vastly different in the case of these other materials.

Mr. Cowett: Therefore, at this stage you're not suggesting that the Screen Brightness Committee recommendation of $7\frac{1}{2}$ plus or minus $2\frac{1}{2}$ ft-L be changed? Is that correct?

Mr. Koerner (written comment supplied for publication): As stated in the paper, we are well aware that other factors in addition to optimum quality must be considered. For instance, the tests which have been described were carried out under favorable projection conditions, and in another paper (immediately following in this *Journal*) Mr. Estes is going to discuss the effect of less favorable project conditions on the choice of a screen-brightness level. We cannot, therefore, recommend a change on the basis of this study alone. We hope that this material will provide additional information which will be weighed along with other factors before a standard is finally fixed. I can say quite definitely that we believe, on the basis of this test and a great deal of experience in our work, that at a screen-illumination level of 5 ft-L much of the quality that is available in a good 16mm Kodachrome print is lost to the viewer.

Maurice J. Merrick (Sawyer's Inc.): Would you say that these results apply without any particular adjustment to arc projection as well as incandescent?

Mr. Koerner: I would think they would, but here again I do not have the data to say that they do so apply.

David B. Joy (National Carbon Co.): Your tests were done on 16mm Kodachrome Film. Would they apply to 35mm film?

Mr. Koerner: I expect that they would.

Effects of Stray Light on the Quality of Projected Pictures at Various Levels of Screen Brightness

By RAYMOND L. ESTES

The influence of stray light on the quality of projected pictures has been studied and data are presented showing the effects at various levels of screen brightness. Changes in the picture reproduction by stray light may easily be confused with poor print quality. From the results observed, it is concluded that a standard of screen brightness may be misleading unless the amount of stray-light brightness is limited to a fixed proportion. These results indicate that for normal projection prints the stray-light brightness of the screen from all sources should not exceed approximately 0.3% of the screen brightness. In the few theaters where measurements have been made, the light resulting from all types of scattering of the projected beam by lens flare, atmosphere, screen and theater walls has accounted for approximately 80% of the stray light on the screen.

WHENEVER pictures are projected on a screen, the brightness range of the screen image from highlight to shadow is established by two limits:

(1) The brightness limit for the highlight is controlled by the light output of the projector in combination with the size and reflection qualities of the screen; and

(2) The limit of darkness is established for any projection screen by its stray-light level. The deep shadow region in the screen image may approach, but certainly cannot be darker than, this lower limit set by the stray-light level.

Presented on April 29, 1953, at the Society's Convention at Los Angeles by Raymond L. Estes, Film Testing Div., Eastman Kodak Co., Rochester 4, N.Y.
(This paper was received on June 15, 1953.)

In one form or another, it is generally recognized that stray light is a problem. Four instances of this are:

(1) A U.S. Navy technician has said, "When a full Bermuda moon rises to flood out our outdoor screen at Hamilton, we're in trouble. Such moons were obviously made for romance and not for the showing of open-air movies."

(2) The Society's Committee on Non-Theatrical Equipment reported in 1941, "Good tonal quality in the projected picture is impossible if the room in which it is being viewed is not adequately darkened."[1]

(3) The National Educational Association stated in a recent audio-visual publication, "Light control is one of the most important of the special problems facing school planners who are

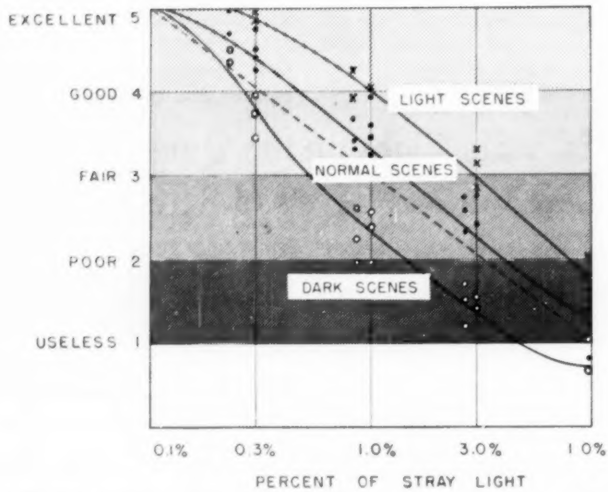

Fig. 1. Quality rating of projected pictures at various levels of stray light by 16 observers on two separate occasions.

designing classrooms to meet the needs of modern education."[2]

(4) A projectionist at a neighborhood theater recently stated that it has been necessary to raise the level of illumination in the auditorium in order to prevent rowdyism.

Therefore, whenever pictures are projected, stray light may become a problem, be it *classroom*, *drive-in* or *theater* screen.

For the purpose of this paper, stray light is defined as the brightness in footlamberts produced on a projection screen by any unwanted, non-image-forming illumination that may be superimposed upon the projection-screen image. Therefore, the maximum possible tonal range for any screen image from highlight to shadow will be contained between these two limits: the screen brightness* and the stray-light brightness. Generally speaking, the greater the difference between these limits, the better will be the conditions for obtaining good quality on the projection screen. Whenever the ratio of these limits is less than 300:1, picture quality for normal density prints will begin to change. A decrease in this ratio to less than 30:1 results in almost total degradation of the screen image. For these last conditions, one may rightly question the visual value of any motion picture for telling a story or educating a group of people.

Data in Fig. 1 show how 16 observers judged the picture quality of several light, normal and dark 35mm motion-picture scenes as they were viewed at various percentage levels of stray-light brightness. Judging was done by numbers which represented the various quality classifications noted on the left side of the graph.

5–4	represents	excellent to good	quality
4–3	"	good to fair	"
3–2	"	fair to poor	"
2–1	"	poor to useless	"

* American Standard Screen Brightness for 35mm Motion Pictures, Z22.39-1944. The brightness at the center of the screen for viewing 35mm motion pictures shall be 10^{+4}_{-1} footlambert when the projector is running with no film in the gate.

The classification of *light*, *normal* and *dark* scenes is the result of analyzing data from many motion-picture prints, both black-and-white and color, which were selected at random over the last five years. The majority of the scenes examined were obtained from actual 35mm theater prints, representing films from many different studios. Measurements were made on all these prints to obtain data concerning the maximum density, minimum density, face density and average density which were used as a further guide in classifying the special scenes selected for the stray-light judgings. The results of these measurements were later compared to those reported by C. M. Tuttle in his paper.[3] These recent results indicate that the average projection density of both black-and-white and color prints has increased somewhat over that reported by Tuttle. The most noticeable change observed was that the average maximum density (Avg D_{max}) of theater release prints is now approximately 3.0 as compared to the 1935 results of 2.4. It should be noted that during the viewing of the various scenes at different stray-light levels, the darker scenes were found to suffer the greatest loss in quality for any given stray-light level compared to the scenes classified as light or normal. This result is common knowledge to the drive-in theater owners where the screen quality of dark murder-mystery pictures is sometimes quite objectionable. A dotted line has also been added to the graph in order to represent the "average print." This line will serve as the standard for picture quality vs. the stray light in the illustrations to follow.

The range in stray-light conditions found in Fig. 1 is known to exist at various times during the projection of motion pictures on outdoor-theater screens as well as in poorly darkened classrooms and auditoriums. It is hoped that this information will bring about a better understanding of how the screen-brightness — stray-light problems affect the picture quality on the projection screen.

The sources of stray-light damage to picture quality can usually be limited to one or more of the following:

(1) Darkened room admitting unwanted light from outside the room or from unsuitable light fixtures in the room.

(2) High reflectance of the projection-room walls and ceiling which reflect the screen light falling upon them back upon the screen. This effect from light-colored surfaces may be quite pronounced in narrow rooms and rooms with low ceilings, whenever the screen occupies a relatively large area at one end of the room, or has one or more sides of the screen in close proximity to a side wall or ceiling.

(3) The light produced by lens flare. In the past few years, the effect of lens flare has been reduced considerably by coating projection lenses, and it is not as great a source of stray light on the screen as formerly. For some lenses, the effect of coating has been to reduce the flare light from the lens by more than two times. Even so, scratches, dust and fingerprints on projection-lens surfaces may cause a large amount of flare light. For outdoor theaters, dust and dirt on projector lenses have to be removed at frequent intervals. Great care should be taken in this operation, because the high grit content in the dust will easily damage the lens surfaces.

(4) Where fairly long distances are involved between projector and screen, scattering by particles in the air gives rise to non-image-forming light which may set a minimum stray-light level on the screen, below which further modifications in theater design and optical equipment cannot be effective.

(5) Moonlight, skylight, scattered light from the projection beam and other sources of illumination, all combine to make up the stray-light level on the outdoor or drive-in theater screen.

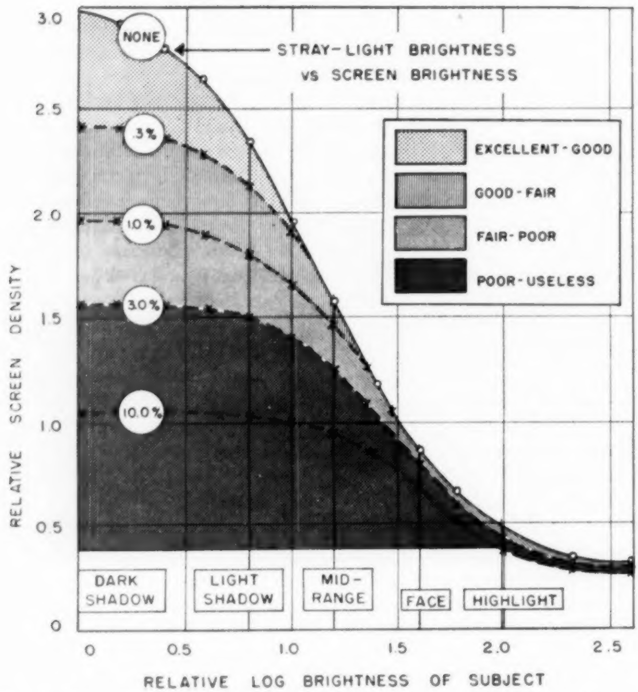

Fig. 2. Stray-light effects on the tone reproduction of an average reversal color print.

Preparation of Test Films

In order to make actual determinations of the stray-light effects on tone reproduction, a neutral-density scale was located in the original scenes being photographed to provide a known gradation of brightness values. Brightness measurements of the density scale were made with a precisely calibrated Luckiesh-Taylor Brightness Meter manufactured by General Electric Co. The measured reflectances of this scale were expressed in terms of *relative log brightness* of the original subject. In addition, intensity-scale sensitometric exposures were also made on the unexposed portion of the same roll of film and were processed along with the camera tests.

After processing, visual diffuse-density measurements of the gray scale were plotted against the corresponding log exposure in the original scene, in order to check the picture tests against the standard sensitometric exposure. Some density differences were observed in the shadow-density region of the picture tests when compared to the D-log E curves of the sensitometric exposure. These small differences were attributed to camera lens flare.

Two pairs of motion-picture films were used in this project for measuring the overall tone reproduction from the original subject to the projected screen image:

(1) Prints on Kodachrome Duplicating Safety Color Film, Type 5265 (16mm), from originals made on Kodachrome Commercial Safety Color Film, Type 5268 (16mm).

(2) Eastman Fine Grain Release Positive Safety Film, Type 5302 (35mm).

from Eastman Plus-X Panchromatic Negative Safety Film, Type 5231 (35mm).

The tone-reproduction curves from the black-and-white prints, as well as those from Kodachrome slide films, which were also investigated, are not included in this report because the results obtained from the projection tests of these films were found to be quite similar to those obtained from the Kodachrome Duplicating Film prints.

The upper curve in Fig. 2 represents the general tone reproduction for the average reversal color print whenever it is projected on a screen free from all stray light. For this condition, a projected color picture matches very closely that observed when the print is viewed in front of an illuminator. The other curves show the degradation in tone reproduction which occurs to the picture on the screen as the level of stray-light brightness is increased to 0.3%, 1%, 3% and 10% of the screen brightness.

The general location of shadow, midrange, face and high-light regions have been added at the bottom of the graph to make it easier to locate these positions on the tone-reproduction curves. It can be noted from studying these curves that stray light lowers the density in the dark shadow areas of the screen image by a much greater amount than in the lighter regions represented by the face and highlight densities.

Calculation of Screen Density

Much information concerning the quality of a projected picture may be obtained from the measurement of its brightness gradations on the screen. The measured brightness tones of the screen image may be presented in terms of screen-reflection density, which will here be called simply *screen density*. The ratio between the brightness of the screen without film in the projector, compared to the brightness of the image, when expressed as a logarithm, becomes a measurement of the reflection density of the image. The relative screen density values (D_s) for projected images reported here are all based upon calculations from the equation,

$$D_s = \operatorname{Log}_{10}\left[\frac{B_s + B_x}{B_I + B_x}\right]$$

where D_s = screen density of an area in the image
B_s = screen brightness
B_I = image brightness for the area being measured
B_x = stray light brightness

For measurements of *stray light* in the projection room, a small, opaque piece of blackened brass was located in the center of the projector gate as close to the film as possible. The area of this opaque object was approximately 5% of the total area of the picture. Measurement of the dark region made by this infinitely dense object on the matte projection screen, therefore, included the factor of lens flare, as well as other forms of stray light present in the room.

It might be well to state again that all these measurements in the projection room were made by the author with a precisely calibrated Luckiesh-Taylor Brightness Meter. When required, calibrated filters were placed in the optical system of the brightness meter to correct the color-balance difference between the screen illumination and the light source of the meter.

Importance of Adequate Screen Brightness

Tone-reproduction curves similar to the previous graph were obtained (Fig. 3) when the stray-light brightness was held constant at 0.1 ft-L, while the screen brightness was varied from 20 ft-L to 5 ft-L. This screen-brightness range represents that recommended by this Society in the Non-Theatrical Equipment Committee Report of 1941, concerning the projection of 16mm films.[1] It is important to note that it is necessary to consider both the stray-light level and the screen brightness in specifications relating to the projection of good quality films.

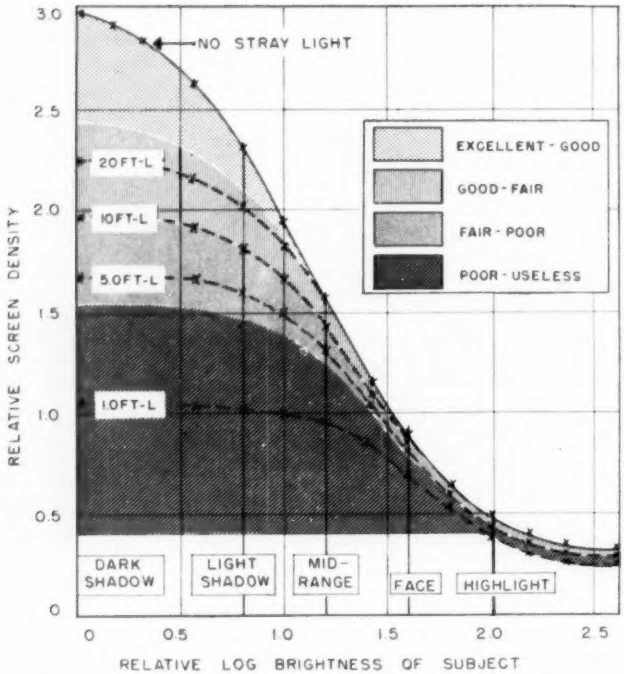

Fig. 3. Tone reproduction of an average reversal color print with a constant stray-light brightness of 0.10 ft-L.

The 0.1 ft-L stray-light brightness on the screen was selected because it has been related by some to the statement that 0.1 ft-c of miscellaneous illumination in an auditorium is not harmful to the quality of projected pictures. Usually, these articles make reference to a paper written by Dr. Loyd A. Jones and published in the 1920 *Transactions* of this Society.[4] In quoting this paper, many people have used his recommendations without qualification and have neglected to state that the information Jones reported was based upon data collected at a screen-brightness level of approximately 20 ft-L. Furthermore, Jones shielded his auditorium lights so that only 0.02–0.04 ft-L of stray light was reflected by the screen as a result of the auditorium illumination. Therefore, the amount of stray light on the screen, which resulted from the level of indirect illumination approved by Jones, represents approximately 0.2% of the screen brightness.

In Fig. 3, it should be noted that the picture quality, represented by the shaded areas, as well as the tone reproduction, denoted by the curves, *drops* when the level of screen brightness is decreased from 20 ft-L to the lower, recommended limit of 5 ft-L. The figure 5 ft-L of screen brightness is important because little more than 5 ft-L can be expected from a standard 16mm incandescent projector on a matte screen, even when the screen is only 10 ft wide.[5] Increasing the picture size to 20 ft drops the brightness to approximately 1 ft-L. Higher brightness levels or larger pictures can be obtained with carbon-arc projectors, but here again for 16mm pic-

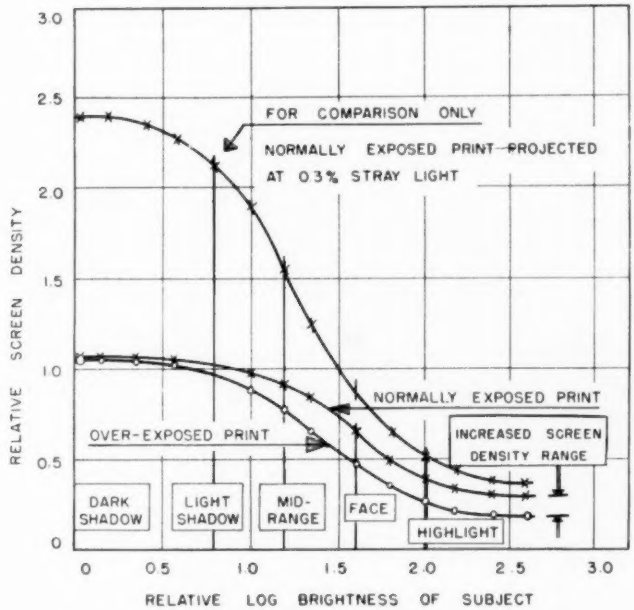

Fig. 4. Projection at 10% stray-light brightness (reversal color prints).

tures the 5-ft-L level is reached at a picture width of about 20 ft. These curves illustrate the importance of maintaining an adequate level of screen brightness and the rapid increase in stray-light problems which occurs whenever the picture size is expanded beyond the light-producing capacity of the projection equipment.

Good picture quality on the screen is important to all who are concerned with the production and processing of films. This includes film and equipment manufacturers as well as those who labor toward bringing to the projection booth the best obtainable motion-picture print. Those who project the films are at the end of a long chain in which everyone must do his part well or success changes to failure.

Specially Timed Light Density Prints

In a desperate attempt to avoid failure where stray-light levels were high, it has frequently been suggested that specially timed, lighter-than-normal prints are the answer. This unfortunate situation needs to be looked at in a very careful manner because it is full of booby traps.

In the lower section of Fig. 4, tone-reproduction curves at 10% stray light are compared for a normally exposed print and a print made intentionally lighter than normal in an attempt to compensate in some degree for this high stray-light level. A slight gain in screen-density range has resulted from the lower highlight density of this lighter-than-normal print. Furthermore, midrange density has been lowered so that it can be distinguished from the maximum densities. Yet, this slight gain will not look very important when considering good picture quality. Picture quality is still very poor when compared to the normal-density print projected at recommended levels of both screen brightness and stray light. The curve at the top

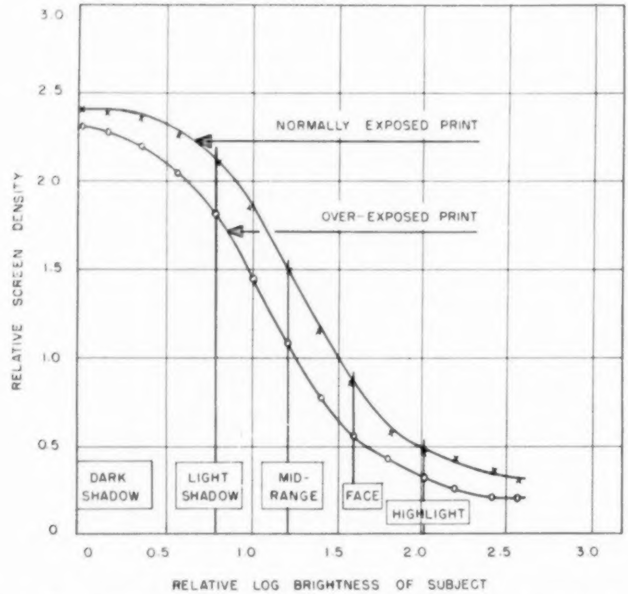

Fig. 5. Projection at 0.3% stray-light brightness (reversal color prints).

was included so that this difference could be easily seen. Obtaining lighter-than-normal prints is not a fruitful way of getting good picture quality on the screen. The desired improvement in screen quality should be obtained by making every effort to increase the difference between the screen-brightness and the stray-light level.

In Fig. 5, the curve marked "Over-Exposed Print" again represents the print made lighter than normal in an attempt to help out those with high stray-light projection problems. The trouble is that this print may also be sent to others where projection conditions are more favorable. When this special low-density print is projected under conditions where the stray-light level on the screen is 0.3% or less, the loss in pictorial quality and color saturation, compared with that usually expected from normally exposed prints, ordinarily causes a number of complaints.

It might be well to emphasize again that the ability to transfer the image on that ribbon of film into a valuable picture for entertainment or educational purposes depends upon the projection conditions under which the print is exhibited.

Stray Light at Drive-in Theaters

Figure 6 illustrates the changes in screen density for five levels of print density as the amount of stray light increases from 0.1% to 10% of the screen brightness. On the outdoor screen, excellent to good projection conditions are not possible on a clear evening, even with the normal-density print, until approximately 50 min after sunset. Some drive-ins start picture projection at 9:00 P.M. EDT during June and July in the Rochester area, and the remainder are in operation before 9:15 P.M. The earliest starting time is approximately 15 min after sunset, and

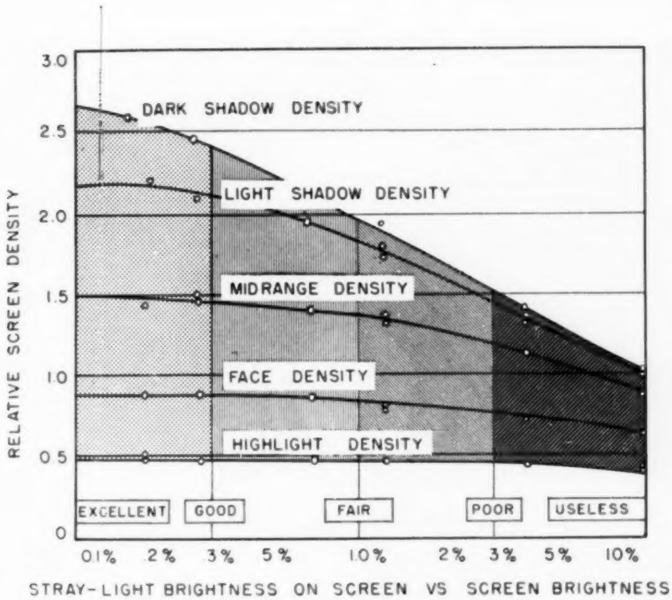

Fig. 6. Stray-light effects on screen density.

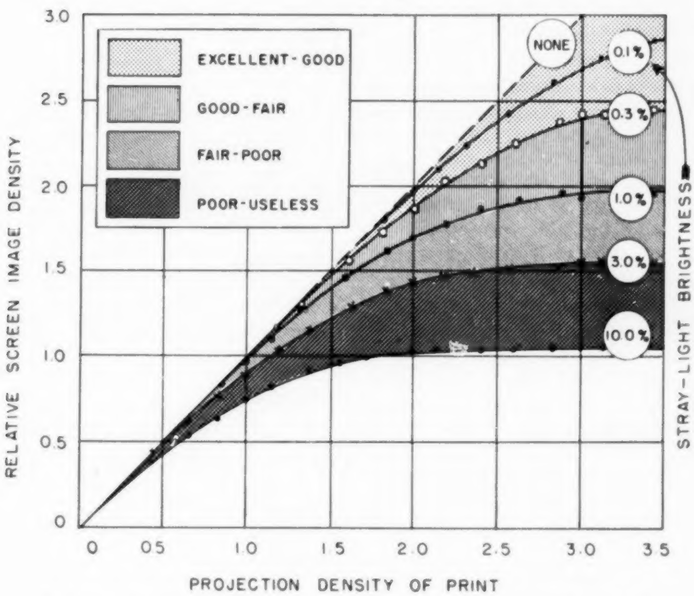

Fig. 7. Screen-image density vs. projection density of the print.

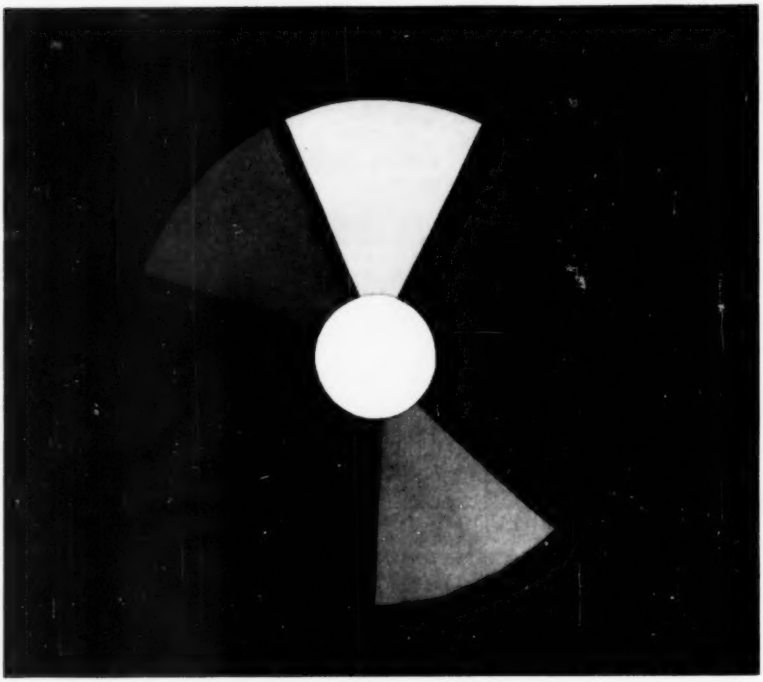

Fig. 8. Chart used in test roll No. 1 to obtain image-transfer data in theater survey. The perforated hole in the center of the picture frame was used to monitor the light output from the projector. The density of the area surrounding the chart was adjusted to attain an overall average projection density of 1.2.

the stray-light level on the screen is actually equal to the screen brightness from the projector. During the period of full moon, the stray-light brightness of the outdoor screen may climb to more than 1% for the average drive-in and probably will exceed 3% for those operating at screen brightnesses in the region of 1 ft-L. Under these conditions, the screen quality of dark prints, typical of murder-mystery films, is discouragingly poor.

Similar fluctuations in the stray-light level are also a problem in other situations, for example, the classroom, even though the quality of the print which is being projected may be classified as excellent. The compression in the screen-density range, as a result of stray light, is most noticeable in the dark-shadow regions of the print, since, in this situation, density is lost much faster than in the light areas. It is not difficult to see why the dark-shadow areas of the picture lose their identity when stray light becomes excessive.

Theater Survey

A direct comparison is made in Fig. 7 between the projection density of the print and its resulting density on the screen at five different levels of stray-light brightness, relative to the screen brightness. Curves similar to these have been obtained from the special test films that are now being used in a

theater and drive-in survey throughout the Rochester area. These curves also agree with those which were calculated mathematically to verify the validity of the experimental data. Anyone may take these data and relate them to a further study of the overall tone reproduction for any motion-picture or slide-film material.

Although the regular and drive-in theater survey has not been fully completed at this time, the following data are given to indicate the trend in the results.

(1) *REGULAR THEATERS*
3 large (over 2,200 seats)
5 small (300 to 1,200 seats)

Average screen brightness at the center of the screen	11^{+6}_{-5} ft-L
Type of screen surface	matte white
Minimum brightness of the screen resulting from the normal operating lights in the auditorium with projector turned "OFF"	$0.006^{+0.001}_{-0.004}$ ft-L
Average stray-light level on the screen during the projection of a normal density print	$0.03^{+0.02*}_{-0.01}$ ft-L, *or* 0.3% of the screen brightness
Average distance from booth to screen (throw)	140^{+55}_{-75} ft

(2) *DRIVE-IN THEATERS*
3 large (capacity of 750 to 1,000 cars)

Average screen brightness at the center of the screen	2.2 ± 0.8 ft-L
Type of screen surface	matte white painted
Size of screen	40 to 60 ft wide
Average distance from booth to screen (throw)	250 ft ± 40 ft
Average brightness of the screen on dark nights with the projector turned "OFF"	0.003 ft-L
Average stray-light level on the screen during the projection of a normal-density print on a dark night. (This does not represent average conditions which would take into account early evening skylight, moonlight, or light scattered from the projector beam by rain, fog or excessive dust in the atmosphere.)	0.017 ±0.004 ft-L *or* 0.8% ± 0.2% of screen brightness

The following data were collected at one drive-in theater where the matte-painted screen faces east directly away from the setting sun. The data are reported for a clear evening in the month of March at 43° north latitude. (During June–July, multiply the time in minutes after sunset by 1.3).

Min After Sunset	*Stray Light on the Screen Relative to a Screen Brightness of 2.2 ft-L*
12	134% —2.95 ft-L stray light
18	41% —0.90 " " "
24	12% —0.27 " " "
30	4.0%—0.087 " " "
40	0.7%—0.016 " " "
50	0.2%—0.005 " " "

The brightness of the screen due to moonlight may reach approximately 0.02 ft-L or 1% of the screen brightness for the average drive-in. When the stray light produced by lens flare and scattered light from the projected light beam is added to that from moonlight, the total amount of stray light is about 2% of the screen brightness. Even higher stray-light ratios occur when there are other large sources of additional stray light flooding the screen, where projection equipment is not in good operating condition, and where the screen brightness is lower than 2 ft-L.

* High stray-light conditions were found in a theater which used a light-colored drape directly behind the perforated projection screen.

Special theater test films were made in order to obtain data concerning the image-transfer characteristics from film to screen density. Test roll No. 1 consisted of a seven-density pie sector chart with a small perforated hole in the center of each picture frame. This perforated hole provided a means for constantly monitoring light output of the projector. An example of this test film is illustrated in Fig. 8. The film used for this test roll was Eastman Color Print, Type 5381, and each density approximated a visual neutral. All measurements to determine the projection density of this film were made in terms of visual arc-quality illumination. The ratio of projection density to diffuse density was found to be about 1.05. The overall average density of this print was controlled at 1.2 to match that of a typical theater release print. The density range represented by the seven areas in this print was from 0.17 to 3.0.

Test roll No. 2 was a composite of 13 black-and-white prints with a special 5-dot density pattern, as illustrated in Fig. 9a and 9b. One dot was located in the center of the picture area while the other four dots were located one-half of the distance from the center to each of the four corners of the picture frame. Each of the five dots was made to the same density in a given print. The dot density in the first nine prints in the test roll ranged from a projection density of 0.04 to 4.2. The density of the background area surrounding the dots in the first nine prints was adjusted for each print so that the over-all density of the print matched that of the typical theater release print. Prints 10 and 11 were made to an average projection density of 0.6 so as to represent lighter-than-normal prints, while prints 12 and 13 were made to an average projection density of 1.6, representing darker-than-normal prints. The dot density in prints 10 and 12 was approximately 2.6, while in prints 11 and 13 it was approximately 3.6. A 30-ft leader having a perforated hole in the center of the picture area was spliced into the roll between prints in order to provide monitoring information on any fluctuations in the light output of the projector arc. Data from these readings were used to obtain greater accuracy in calculating screen density. The ratio of projection density to diffuse was found to be 1.25 to 1.30 for this film.

Measurement of the stray-light conditions in regular and drive-in theaters with this test roll showed the following results:

	Stray Light in Theaters	
Type of Print	*Regular*	*Drive-In*
Lighter-than-normal	0.7%	1.3%
Normal density	0.3%	0.7%
Darker-than-normal	0.2%	0.4%

Cross-over data between the two test rolls were found to be in excellent agreement.

Summary

There are four important points which relate to the screen quality of projected pictures. They are:

(1) Screen quality is largely dependent upon the ratio of limits established between the screen brightness and the stray-light brightness on the screen. The results show that the stray-light ratio should not be greater than 0.3% of the screen brightness.

(2) Stray-light problems increase as screen brightness is lowered. This is important to those who attempt to expand the size of the projection screen beyond the light-output capacity of the projection equipment.

(3) Dark scenes are affected more severely by stray light than are light or normal-density scenes. The presence of very dark scenes is of some concern to managers of drive-in theaters where moonlight and other forms of stray light are a continual, uncontrollable problem. Similar problems also exist in

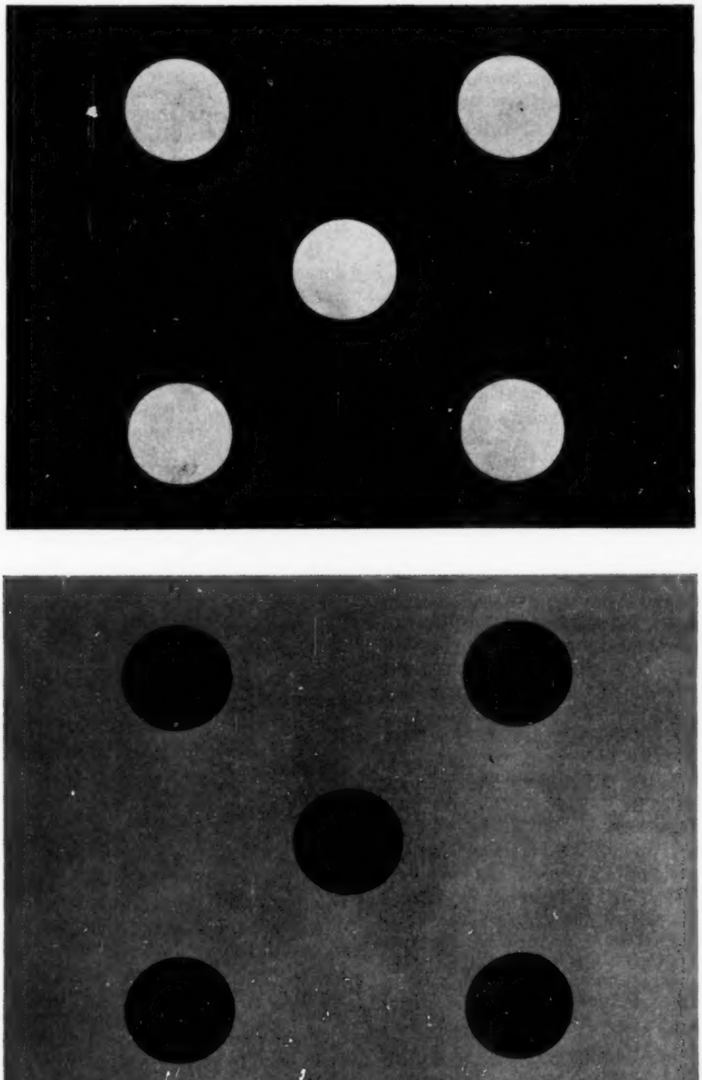

Fig. 9. Chart used in test roll No. 2 to obtain image-transfer data from five locations on the picture screen for the theater survey. (Above) An example of a print in which the density of the dots is less than the overall average projection density of the print. (Below) The density of the dots in this print is greater than the overall average projection density of the print.

classrooms not equipped with the proper room-darkening facilities.

(4) It is recommended that this Society should consider the formulation of a screen brightness vs. stray-light recommendation for auditoriums, classrooms and review rooms, possibly based upon the tone-reproduction data that have been compiled for this paper.

Acknowledgments

The work described in this paper was done with the cooperation of a great many associates at Eastman Kodak Co. The theater survey was made possible by the interest of the Projectionists' Local #253 IATSE, the Stage Employees' Local #25 IATSE, the owners and managers of the Rochester theaters involved, and the cooperation of the SMPTE Screen Brightness Committee.

References

1. "A report of the Committee on Non-Theatrical Equipment," *Jour. SMPE, 37:* 22–69, July 1941.
2. *Classrooms*, No. 1 of the Series *Planning Schools for Use of Audio-Visual Materials*, Dept. of Audio-Visual Instruction, National Education Assn., 1201 Sixteenth St., N.W., Washington, D.C., pp. 1–34, July 1952.
3. C. M. Tuttle, "Density measurements of release prints," *Jour. SMPE, 26:* 548–553, May 1936.
4. Loyd A. Jones, "The interior illumination of the motion-picture theater," *Trans. SMPE, 10:* 83–96, May 1920.
5. W. H. Offenhauser, Jr., *16mm Sound Motion Pictures*, 1st ed., Interscience Publishers, New York, 1949, Chap. XIII, pp. 450–451.

Discussion

Russell W. Bemis (*UCLA, Arch. & Eng. Dept.*): This problem of stray light during the projection of films in classrooms has confronted us for some time, especially in connection with the new building program. The Committee on Screen Brightness, Audio-Visual Education, and I have examined many classrooms throughout the city and have found no real solution for the satisfactory elimination of excessive stray light. What conditions have you found in the eastern areas, and what type of shades or shutters are they using to block out the stray light?

Mr. Estes: I have visited only a few audio-visual classrooms in the Rochester area. Here they use double window-shades of the pulldown type to darken their rooms. Efficiency of the system is improved by having both sides of one of the shades travel in a U-shaped channel. The system works well on dull days, but not on bright days when the sun shines on the windowed side of the building. For further information on darkening classrooms, may I refer you to the booklet, "Planning Schools for the Use of Audio-Visual Materials," which has been recently published by the Dept. of Audio-Visual Instruction, National Education Assn., Washington, D.C. I believe that you will find it has some very worthy material in it.

Mr. Bemis: We have examined drapes, pulldown curtains, and the new louvered shutters which have recently been installed on the outside of the windows in the new school at Glendale. At this school, they project directly onto a wall painted a pale blue-green. We have found that we get the best picture in color or black-and-white when the projected picture is located to one side of the windowed area, where the light does not fall directly on the screen. However, I am grateful for your suggesting the book.

Lawrence F. Brunswick (*Colorvision, Inc.*): Where the ambient light is high and stray light is a problem, would the use of the specular reflective-type screen (metallically coated) offer a possibility of benefit in two directions? First, less-apparent brightness from the ambient light itself; and second, a gain in the brightness of the projected image because of the highly directional characteristics of the screen. There would be some sacrifice, of course, in the angle of viewing. However, has that been considered in certain applications?

Mr. Estes: When you raise the screen brightness to a higher level, and at the same time drop the effective stray light on the screen to a lower level, the result should be an improved picture. Whatever you do to increase the difference between the stray-light brightness and the screen brightness will benefit the density range of the projected picture. Table viewers for 35mm

slides are designed to give very high screen brightness in order that they may be successfully used in offices where stray light is abundant.

Mr. Brunswick: In that case, then, would the type of screen that I'm referring to (it's the type of screen used for stereo projection) be beneficial?

Mr. Estes: In certain situations, this type of screen might be quite beneficial. However, the Committee on Non-Theatrical Equipment of this Society in 1941 made several recommendations regarding the use of various types of screens (diffuse, semi-diffuse, and specular) due to variations in their light distribution characteristics. From their recommendations, it appears that one should be quite careful when selecting a screen for a classroom, to make sure that it meets all the requirements.

In the two previous papers, the proper levels of screen brightness have been carefully specified after much study. The real purpose of this paper has been an attempt to demonstrate why stray-light levels should be reduced to a maximum of 0.3% of the screen brightness, in order to obtain good picture quality at the specified levels of screen brightness.

Philip M. Cowett (Bureau of Ships): Previous to this session, Mr. Ryder of Paramount Pictures presented a paper entitled, "Brighter Pictures for Drive-Ins." He stated that Paramount was going to lighten all their pictures so that they may be used equally well in drive-ins and regular theaters. I think that this is significant, especially in view of the fact that you have shown that stray light affects lighter pictures much less than darker pictures. Let's say that you're recommending a screen-brightness level of 10 ft-L, but we in the Navy aren't able to obtain a brightness level of 10 ft-L on the projection screen. I think that this is also true with a great many other users of 16mm films. Therefore in order to achieve a good show, there will have to be some compromise with regard to screen brightness and print density.

Mr. Estes: This Society, the film and equipment manufacturers, as well as many others involved with the production and processing of films have always been extremely interested in obtaining good quality pictures on the screen. Certain standards of screen brightness were recommended by this Society to help the industry attain this result. Due to the wider use of films in recent years, there have appeared numerous incidents where this standard has not been met, and problems have arisen.

What I have purposely done in presenting this paper was to review with you the factors effecting the sensitometric characteristics of the projected image so that a better understanding would be possible concerning the relationship between per cent stray light and the density transfer characteristics of the projected image. I hope that everyone will use this information wisely and apply it towards obtaining the best in picture quality for both 16mm and 35mm installations.

Max Pulejo (Fulbright Student, USC): I am speaking now from the viewpoint of the cameramen in my country, outside the U.S.A., who are resentful when they go to a theater and find what they endeavored to put on the film is not on the screen. Since this condition varies a great deal from one theater to another, due perhaps to the color of the room or the tendency for light walls in modern architecture, would you recommend any method to fight this stray-light situation?

Mr. Estes: That is a rather complicated question. It will take some time to consider all aspects. I'd rather not answer your question at this time.

John P. Breeden, Jr. (Ford Motor Co.): Could you give your recommendation for the minimum allowable ratio between screen brightness and stray light?

Mr. Estes: My recommendation is that the level of stray light be maintained at not more than 0.3% of the screen brightness. I am certain that if you will follow this suggestion, you will never be troubled by stray-light problems.

Ben Schlanger (Architect, New York City): This stray-light problem in the interior of motion-picture theaters has been licked for quite some time now. It has almost become a standard method of lighting in an auditorium to use the downlight system in which the light does not fall on any place but the audience and does not fall on any wall which might re-reflect the light back to the screen. So far as school rooms are concerned, where you must prepare very rapidly for showing a motion picture, and where other work is being done all day long, the rear-projection unit which I saw in England was very nice. The rear-projection

method will give you a lot less trouble in rooms where you have stray light. In school rooms where the room is used more regularly for motion-picture projection, means for cutting out stray light, of course, are provided. Of course, the drive-in theater is again a special problem. Some day they hope to use rear projection there also to reduce the stray-light problem.

In answering this gentleman from another country, while there is a tendency to have lighter walls in modern architecture, we now know how to design the walls of the motion-picture theater and keep them as light as we want to in color. You can even use white, if you want to, providing that a texture is used on the wall which controls the light coming from the screen so that when it's re-reflected, it's re-reflected transversely across the room or back into the eyes of the viewer, but never back to the screen.

However, these new ideas are not new anymore, they are at least 10 years old. They haven't been applied too many times. But there are many examples of them, and stray light is really not a problem in a modern motion-picture theater.

Mr. Estes: In the theaters that I have surveyed, I will agree with you in that stray light has not been a problem there.

David B. Joy (National Carbon Co.): I have a question. But first I would like to express my appreciation, and I think the appreciation of all of us in the exhibiting end, on these three papers that have just been given. I think the data here are fundamental, and I think they're going to be of great use in improving the quality and showing of our pictures. I would like to say one thing about what Ben Schlanger said. I think that it is true that in some theaters we don't have a stray-light problem, but I think, from experience, that there are a good many theaters where there is a stray-light problem. The question I would like to ask is this: Would this same stray-light limit ratio of 0.3% of the screen brightness apply in general to 3-D pictures as well as to 2-D?

Mr. Estes: I haven't made any 3-D surveys. However, I believe that the recommendation would apply also to 3-D installations. Just recently in one of the Rochester theaters, where they have gone to 3-D, I made a quick measurement of the screen brightness. I found that the normal operating brightness of 10 ft-L was reduced by the polarizing filters used in front of the projector lens to a screen brightness of approximately 3 ft-L. This means that the use of polarizing filters reduces normal screen brightness by approximately three times.